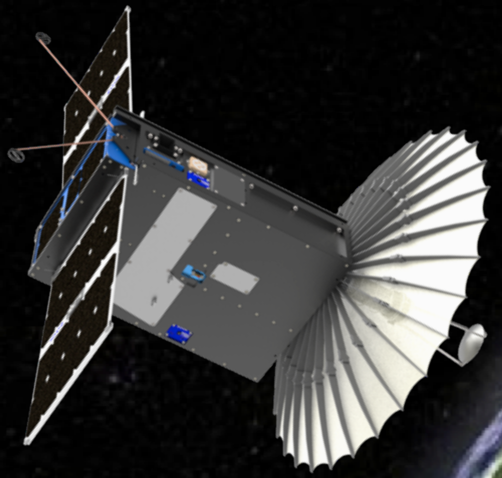
RainCube the First Spaceborne Precipitation Radar in a 6U CubeSat: From Concept to Mission

Jet Propulsion Laboratory
California Institute of Technology



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for the RainCube team at JPL and Tyvak

9th Conference on Transition from Research to Operations
AMS 99th Annual Meeting Jan, 2019

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RainCube

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Shin	Yamamoto
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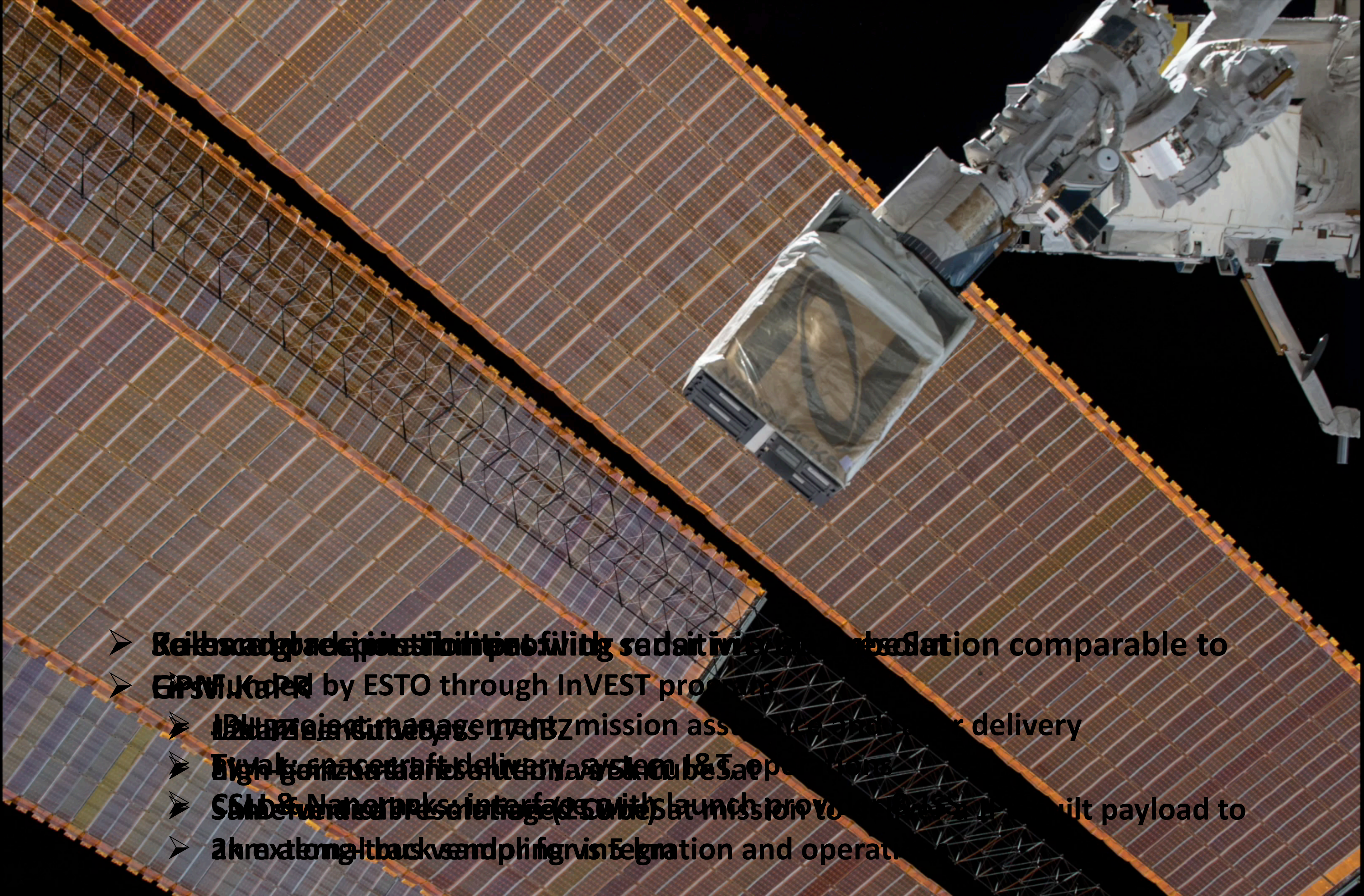
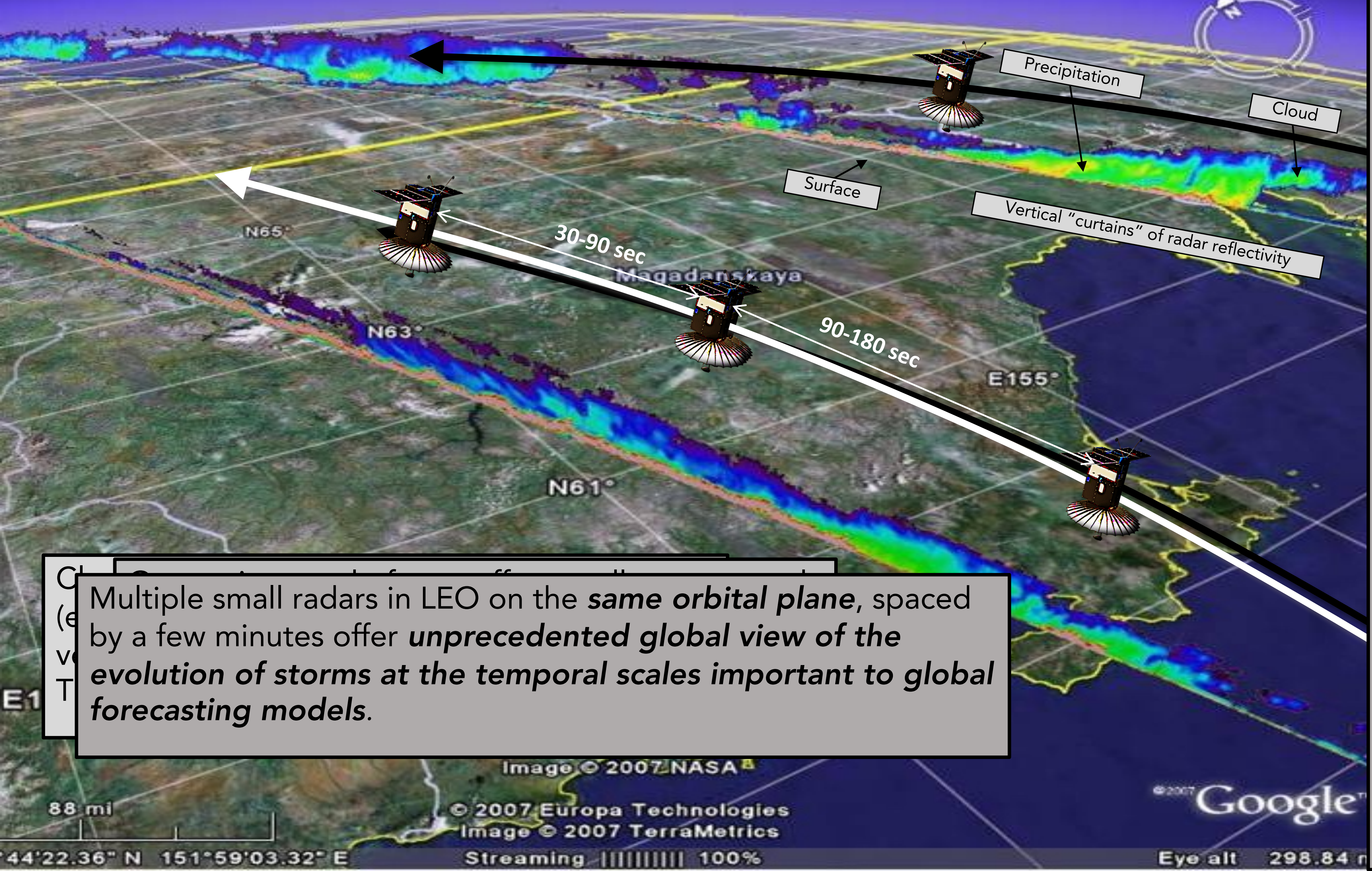

mission comparable to
by ESTO through InVEST pro
mission ass delivery
ult payload to
ation and operat

Observing Cloud and Precipitation processes from space



Multiple small radars in LEO on the ***same orbital plane***, spaced by a few minutes offer ***unprecedented global view of the evolution of storms at the temporal scales important to global forecasting models.***

Inquiries for the feasibility of multiple cloud & precipitation radars in LEO were formulated during the development of TRMM and CloudSat (late 90's and early 00's).

Instrument and bus unit costs, and launch costs, didn't enable a realistic path to even propose such mission architectures…

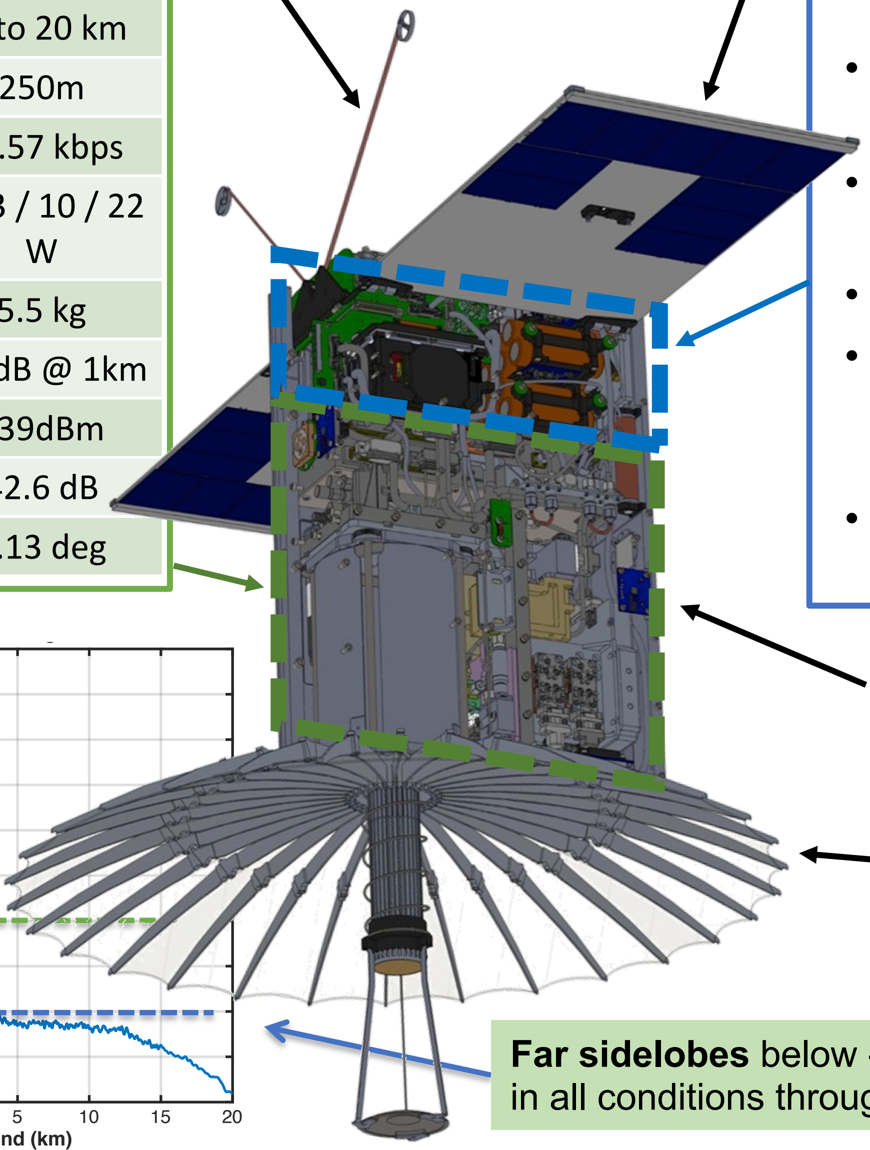
until the CubeSat (Nano, Micro, Small, …) revolution.

First challenge was posed with 1U and 3U (no-go). Then the 6U became an option…

System Architecture

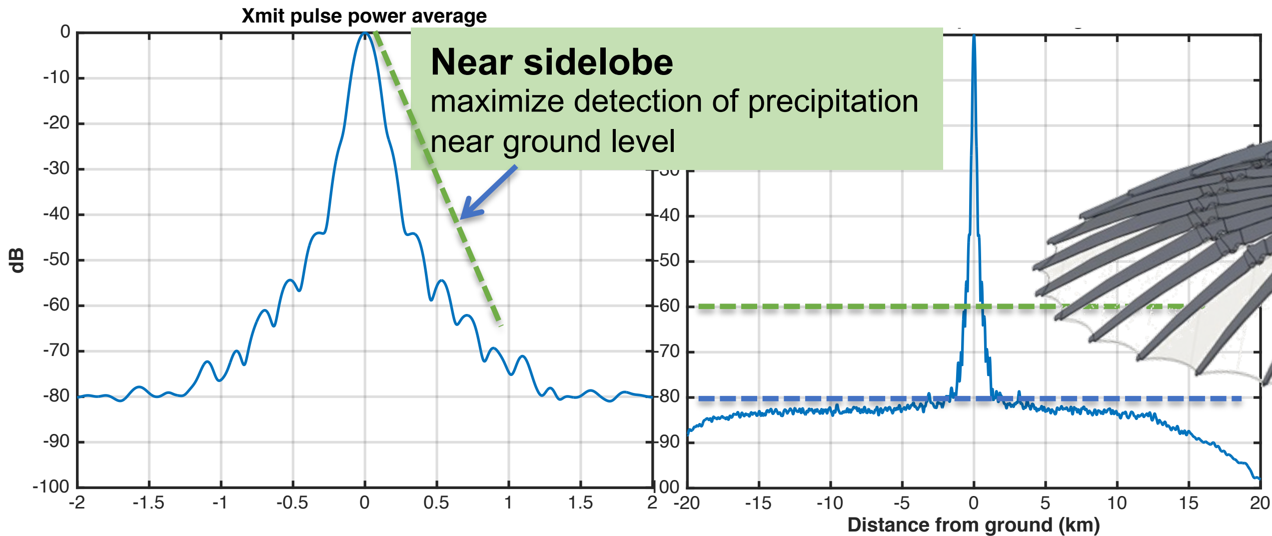
Radar Electronics & Antenna Reqs. (4U)

Req't Name	Requirement	Measured
Sensitivity @400km	20dBZ	11.0dBZ
Horizontal resolution @400km	10km	7.9 km
Nadir Data Window	0-18 km	-3 to 20 km
Vertical resolution	250m	250m
Downlink data rate (in transmit)	50 kbps	49.57 kbps
Payload power consumption (AntDeployment/STDBY/RXOnly/TXScience)	10 / 8 / 15 / 35 W	5 / 3 / 10 / 22 W
Mass	6 kg	5.5 kg
Range sidelobe suppression	>60dB @ 5km	>65dB @ 1km
Transmit power & Transmit loss	10W / 1.1dB	>39dBm
Antenna gain	42 dB	42.6 dB
Antenna beamwidth	1.2 deg	1.13 deg

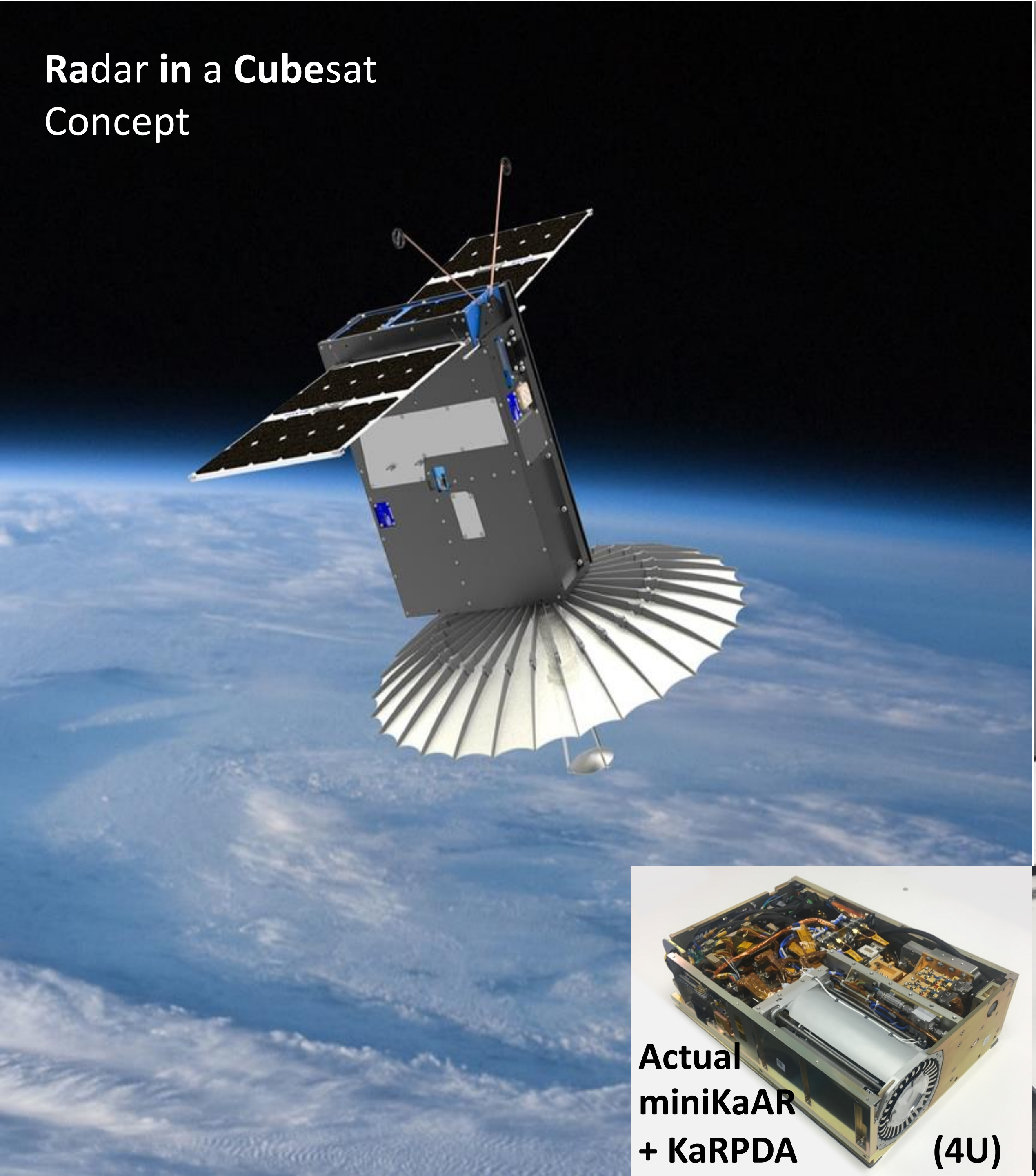


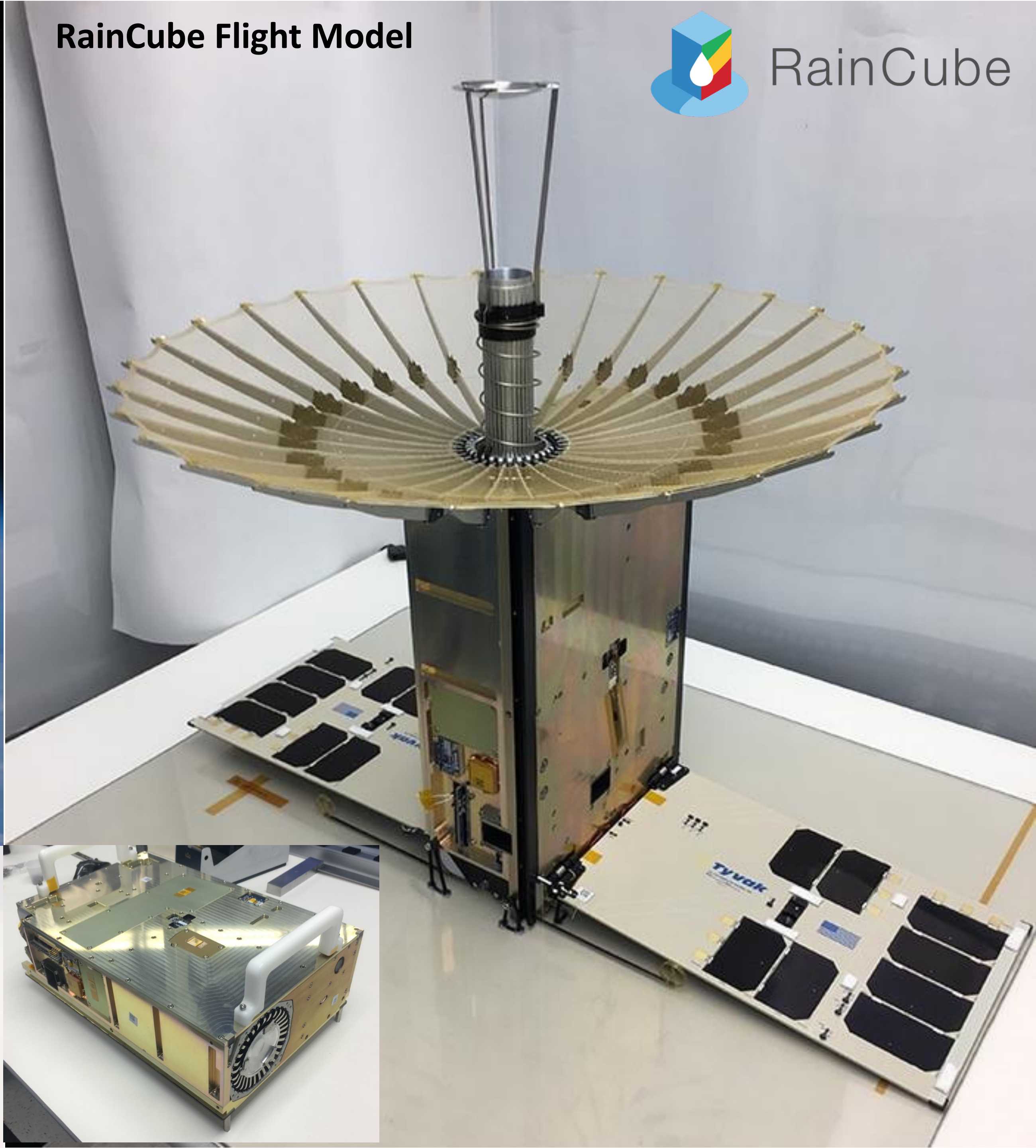
Bus Reqs. (2U)

- Provide 35 W for payload power in transmit mode
- Maintain a 25% radar duty cycle
- 12.1 Gb/week of payload data
- Maintain payload temperatures (-5C to +50C operational)
- GPS provides on-board altitude to radar

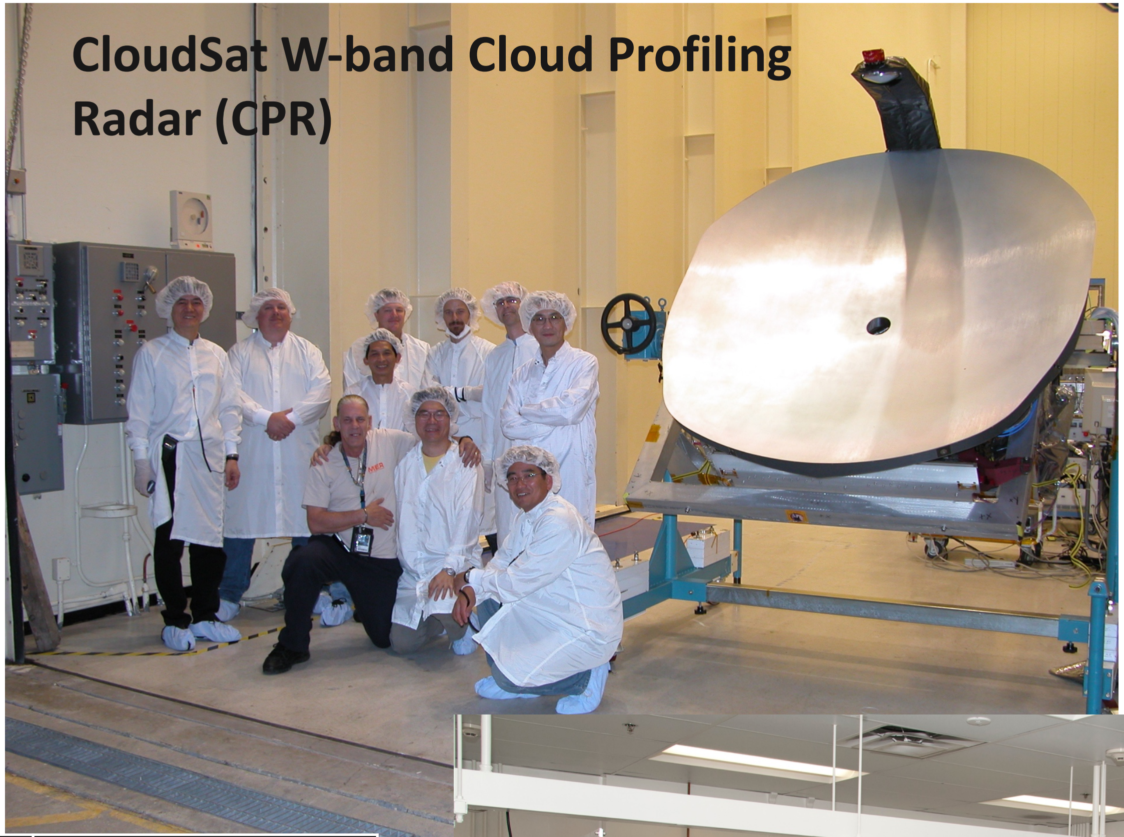


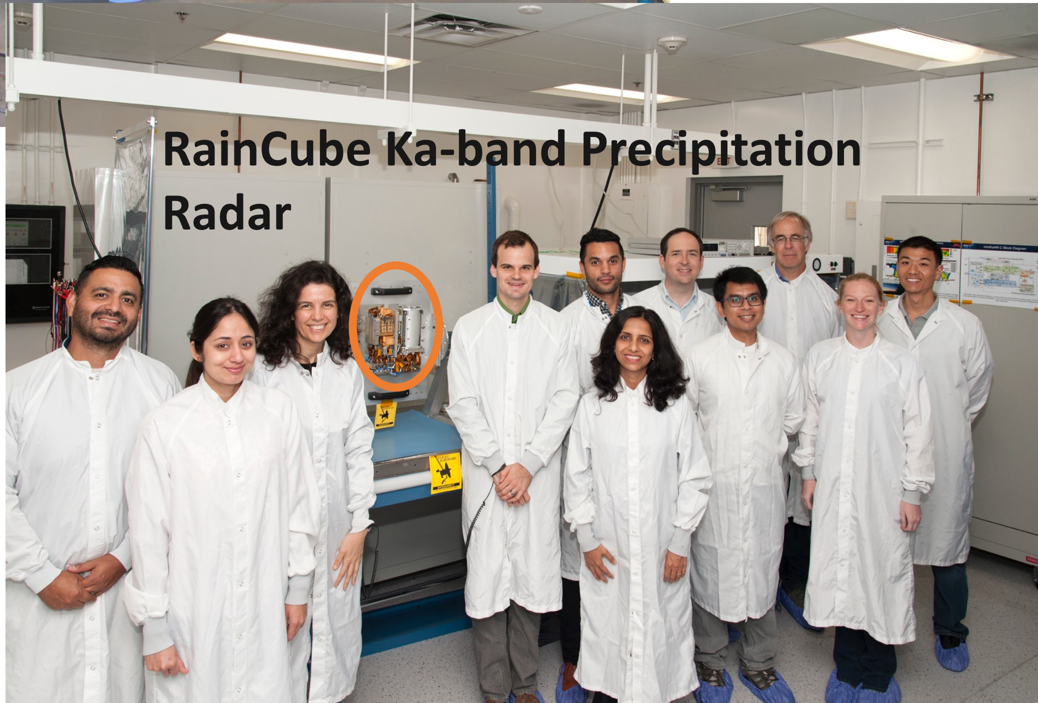
Far sidelobes below -60dB for clutter-free detection in all conditions throughout the troposphere


Radar in a Cubesat
Concept
Actual
miniKaAR
+ KaRPDA
(4U)


RainCube Flight Model
RainCube

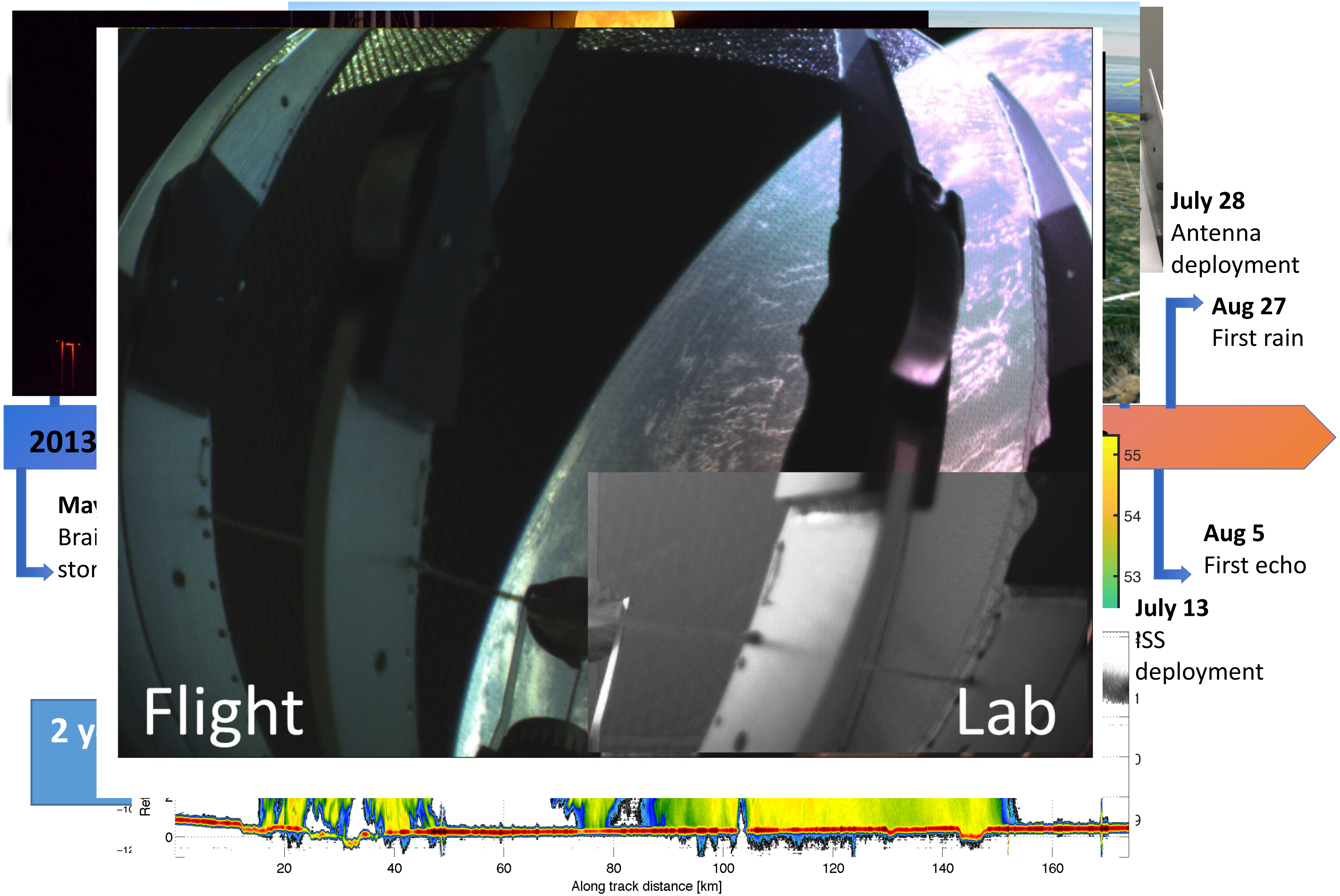
How small is RainCube. . .





	CPR	KaPR	RainCube
Mass [Kg]	260	336	7
Power [W]	300	344	22
Volume [U]	4,356	1,210	4
Class	C	C	Tech demo
Frequency	W-band	Ka-band	Ka-band
Scanning	No	Yes	No
Sensitivity	-30 dBZ	+17 dBZ	+12 dBZ

Timeline from TRL 0 to TRL 7

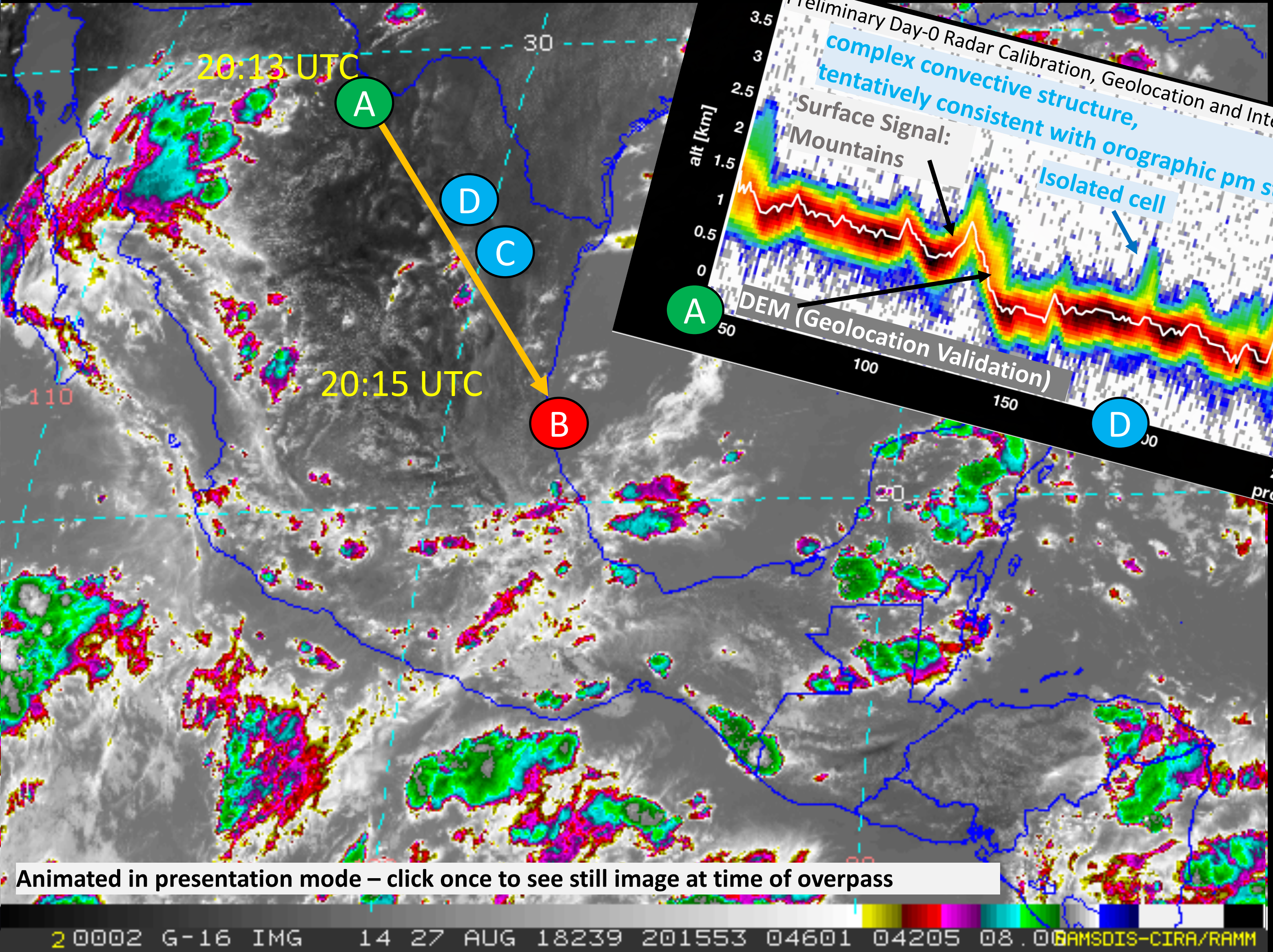


RainCube Tx Operation #23 - August 27 , 2018 – 20:14 UTC

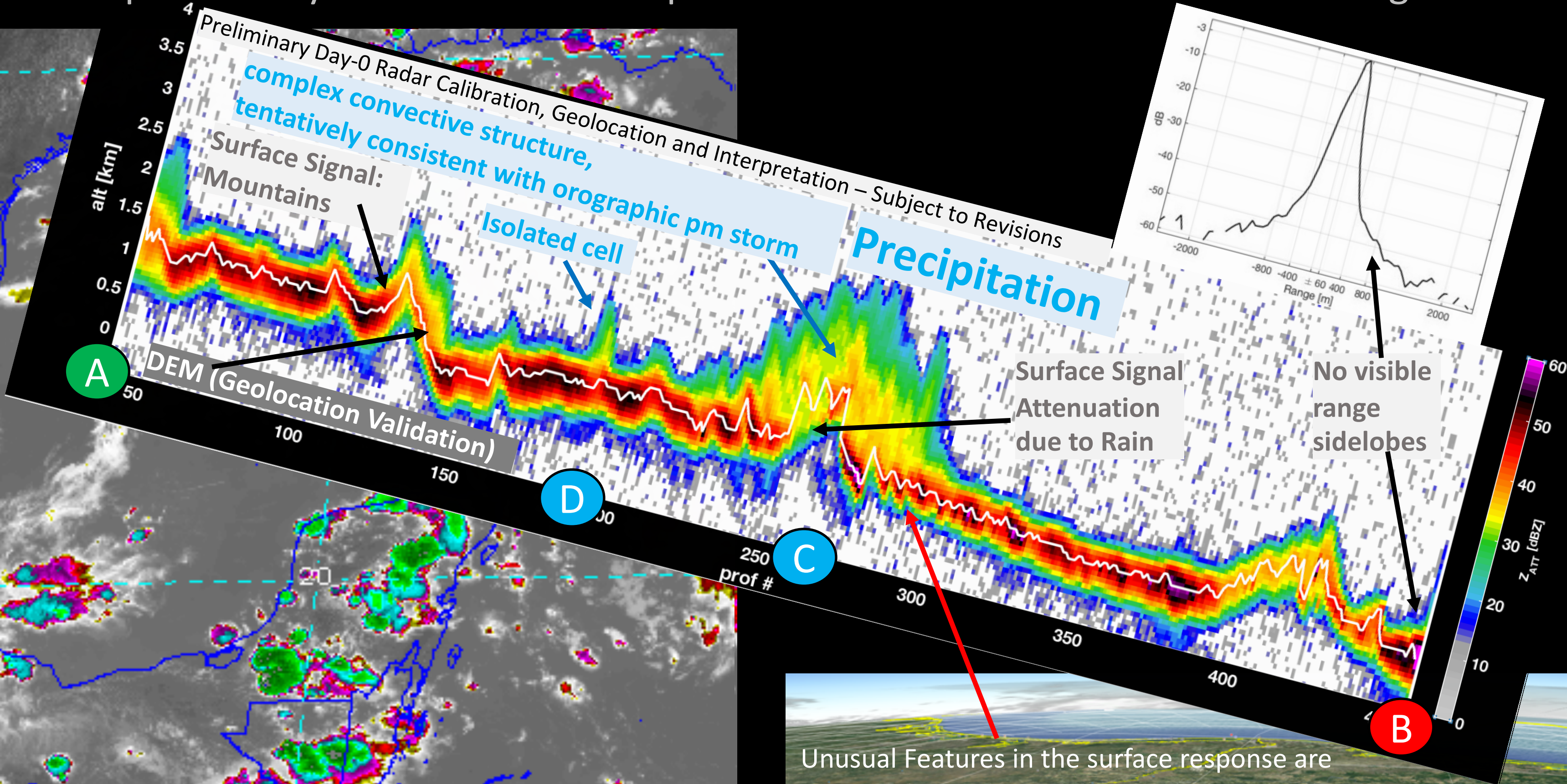
Jet Propulsion Laboratory
California Institute of Technology

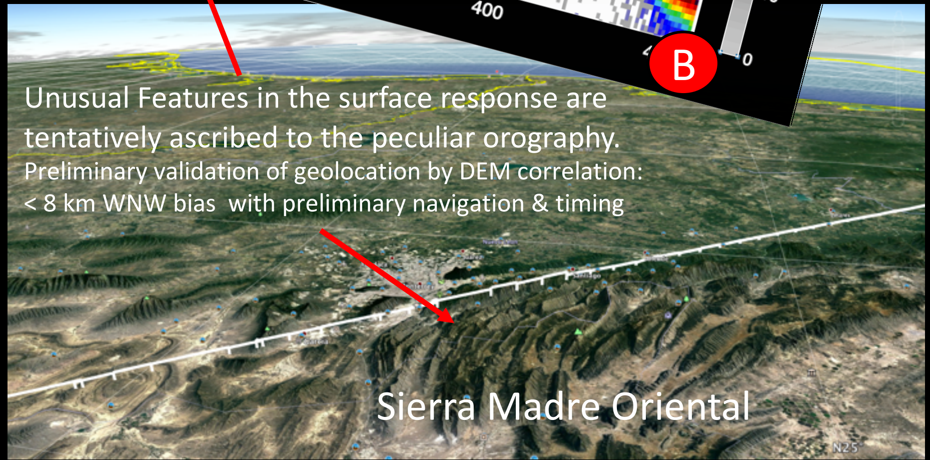
RainCube

First successful operation in Nadir Pointing & first detection of rain over the Sierra Madre Oriental, near Monterrey, Mexico.
Fast growing orographic precipitation developed shortly before RainCube's pass which overflew its north-eastern edge

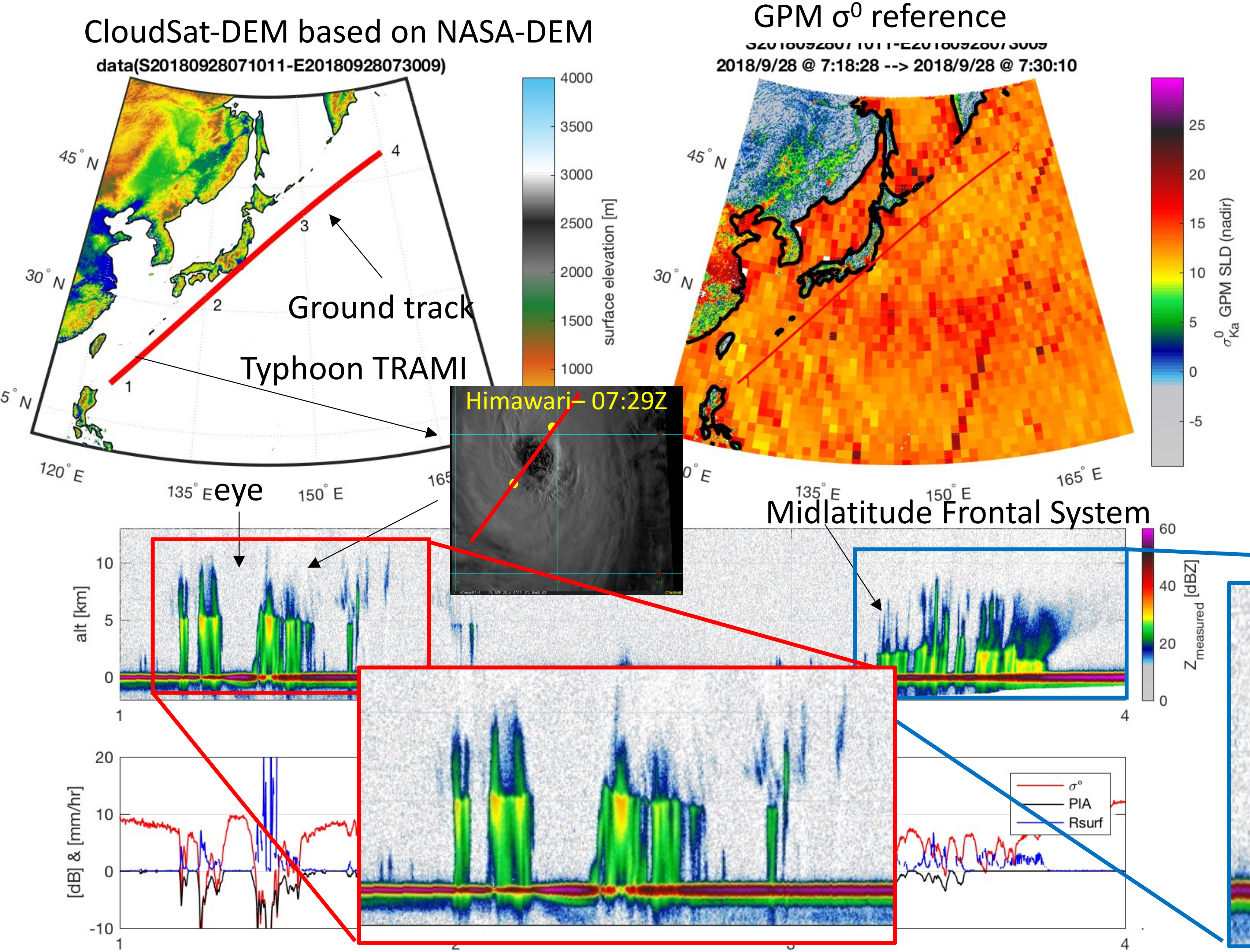


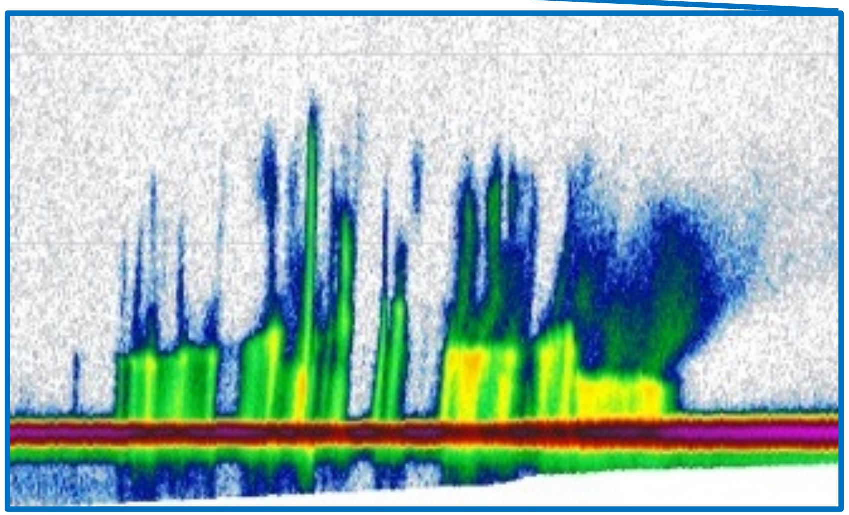
Animated in presentation mode – click once to see still image at time of overpass





RainCube – September 28, 2018





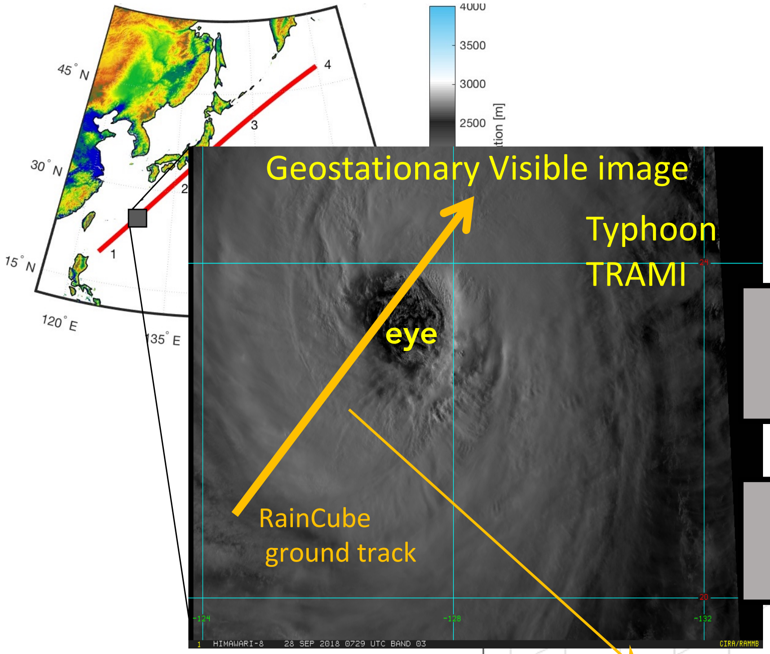
Structure of Typhoon TRAMI

Shortly after it had weakened from Cat 5 to Cat 2. The SW-NE cross section shows very little convective activity along the eyewall (mostly located in the SE sector at that time).

Mid-Latitude system with deep convection

The complex structure of this frontal system propagating NW from Japan includes deep convective towers reaching almost 9 km and sharp gradients of the zero isotherm height.

RainCube and TEMPEST-D observe Typhoon Trami on Sept. 28, 2018



RainCube
6U Ka-band
(35.7GHz) nadir
pointing radar

~5 min apart

Tempest-D
6U multi-channel
microwave
radiometer

Novel ultra compact architecture, high performance pulse compression

Novel ultra compact architecture, high quality calibration

1D Horizontal structure, 250 m vertical resolution

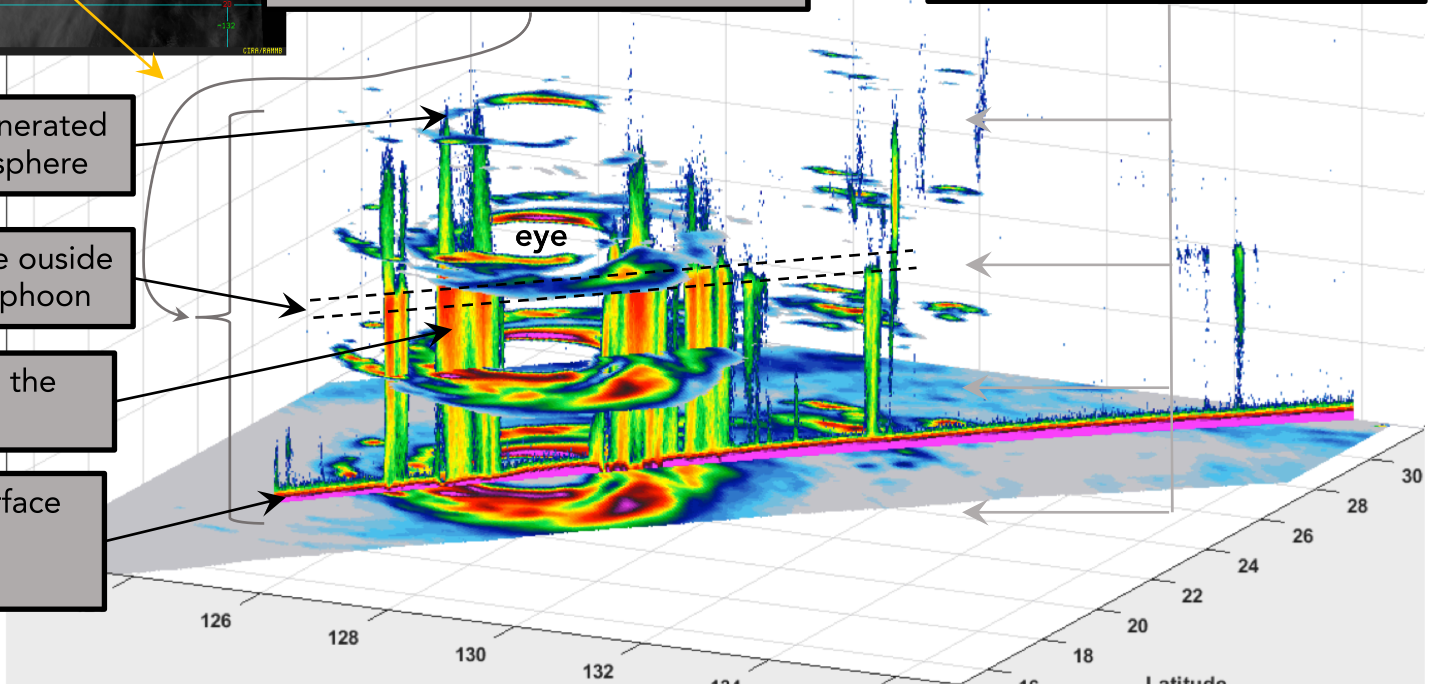
2D Horizontal structure, 4 vertical levels

Extent of penetration of ice generated by convection in upper troposphere

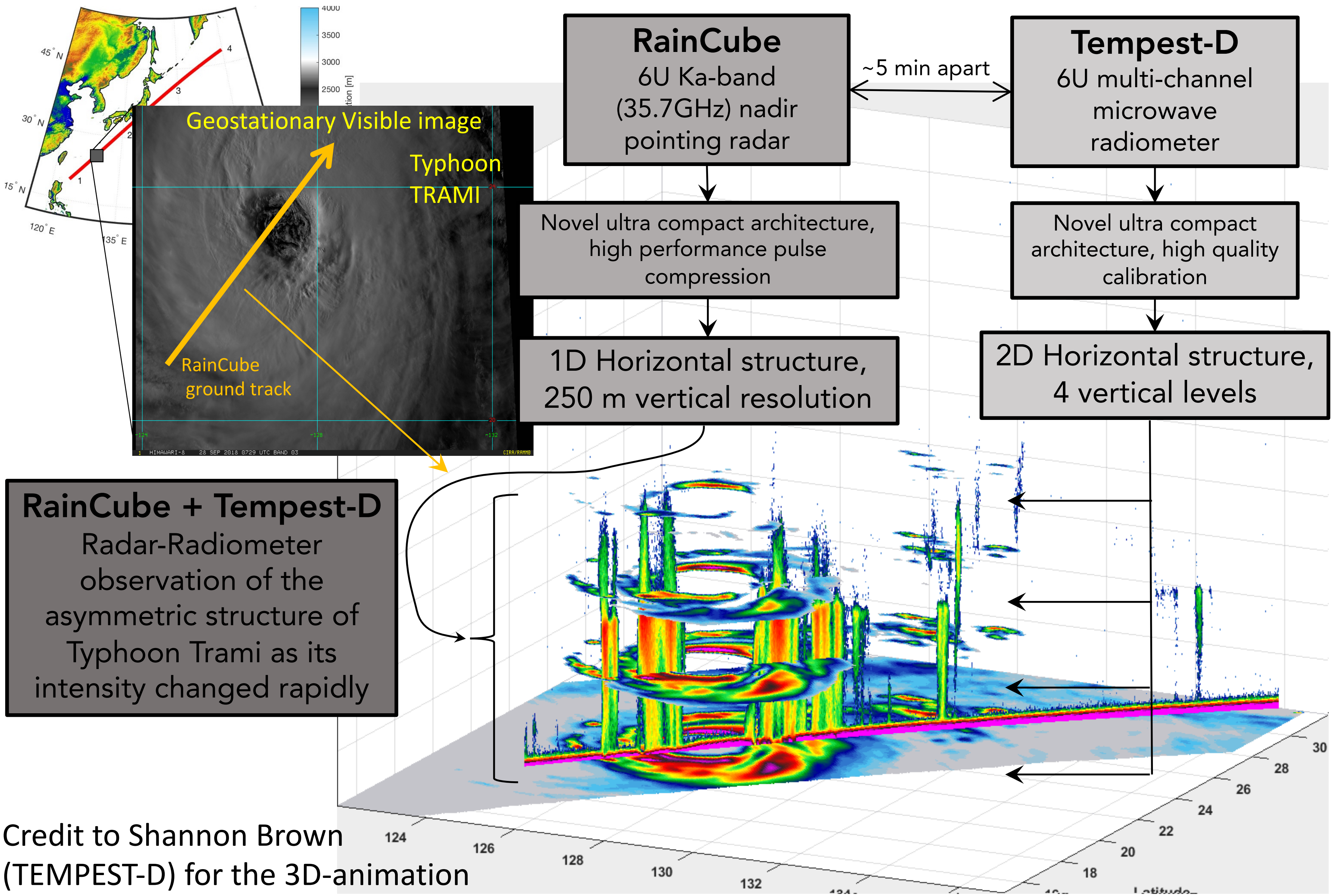
Melting Layer : ~4.8 km altitude ouside of TRAMI, raised inside the Typhoon

Intensity of precipitation in the eyewall and rainbands

Strong echo from ocean surface does not contaminate precipitation echo



RainCube and TEMPEST-D observe Typhoon Trami on Sept. 28, 2018

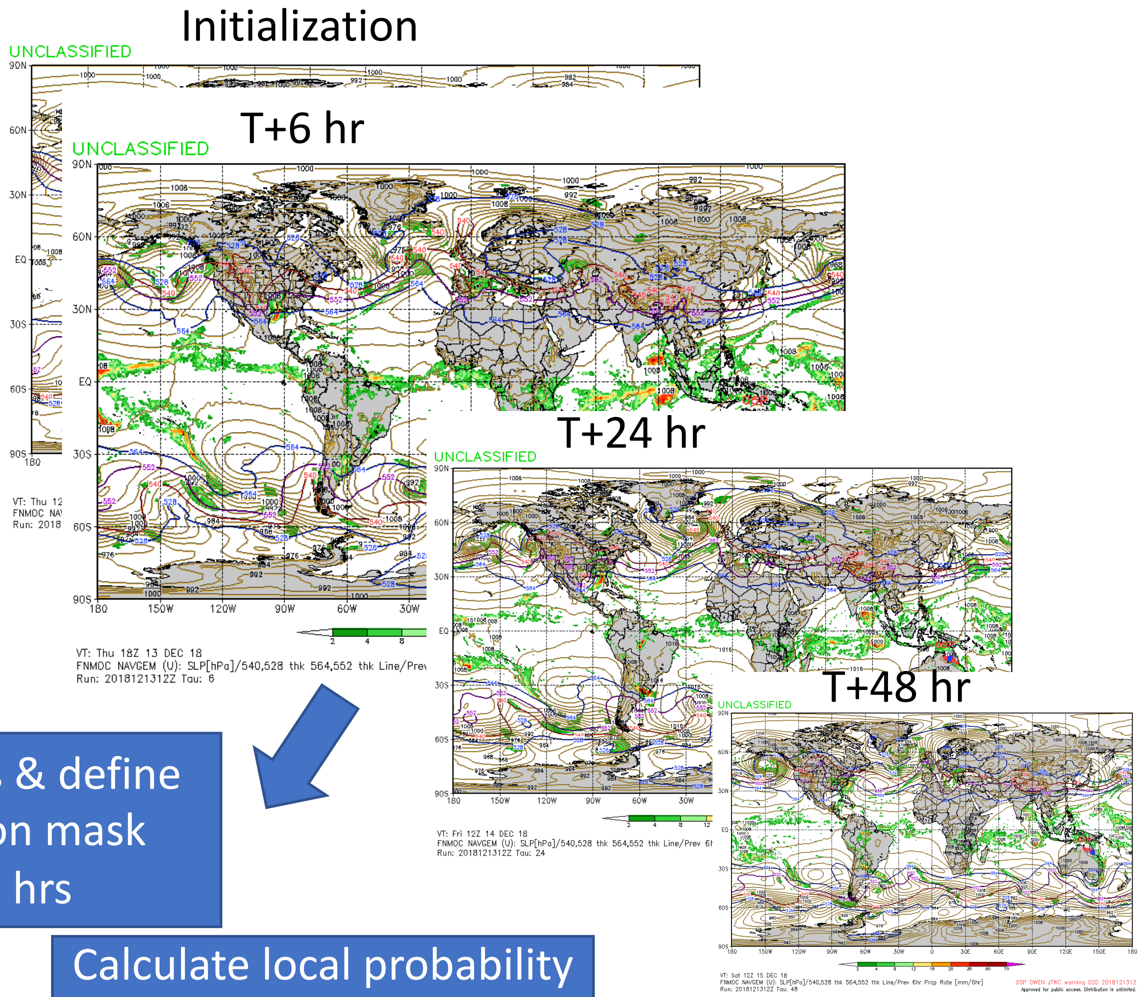


Credit to Shannon Brown (TEMPEST-D) for the 3D-animation

Science Operations Planning

Need to automate the planning of events in a prioritized way

- Constraints
  - Maximum of 6 20 minute Radar Acquisitions per day
    - Imposed by spacecraft power system
  - No operations on consecutive orbits
    - Imposed by spacecraft power system
  - No operations in umbra
    - Preferred because of higher occurrence of reboots in umbra
- Priorities
  - Forecasted presence of precipitation
  - CONUS – for NEXRAD
  - GPM – for DPR
  - Storms of interest



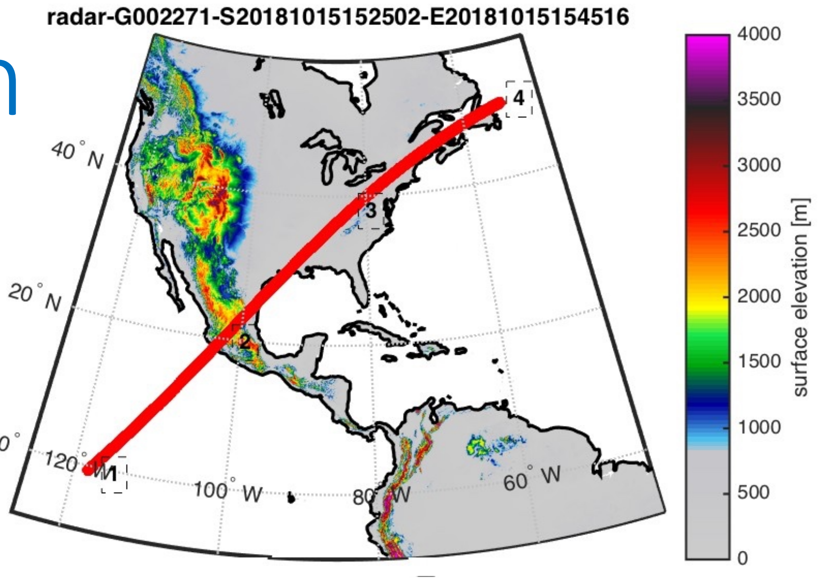
Parse images & define precipitation mask every 6 hrs

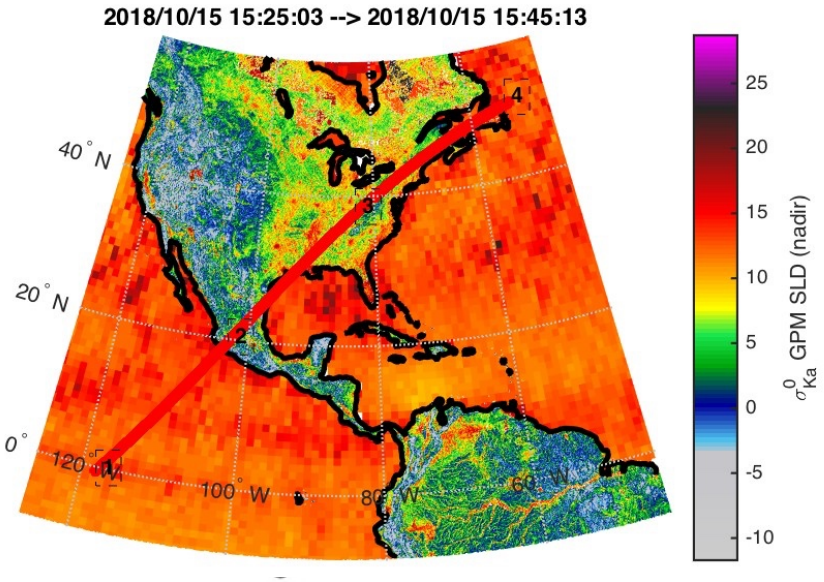
Calculate local probability of precipitation along the predicted orbit of RainCube

Prioritize close approaches with GPM and passes over GPM GV sites (CONUS, Japan, Australia)

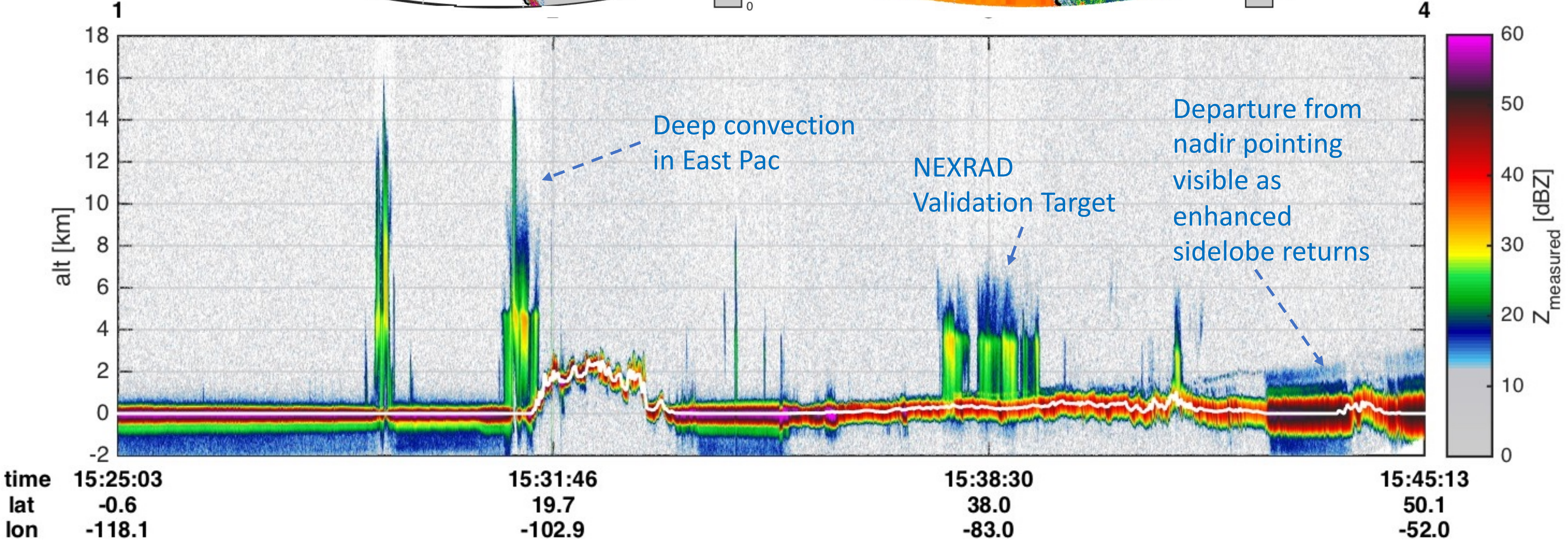
Validation

High-resolution DEM from CloudSat



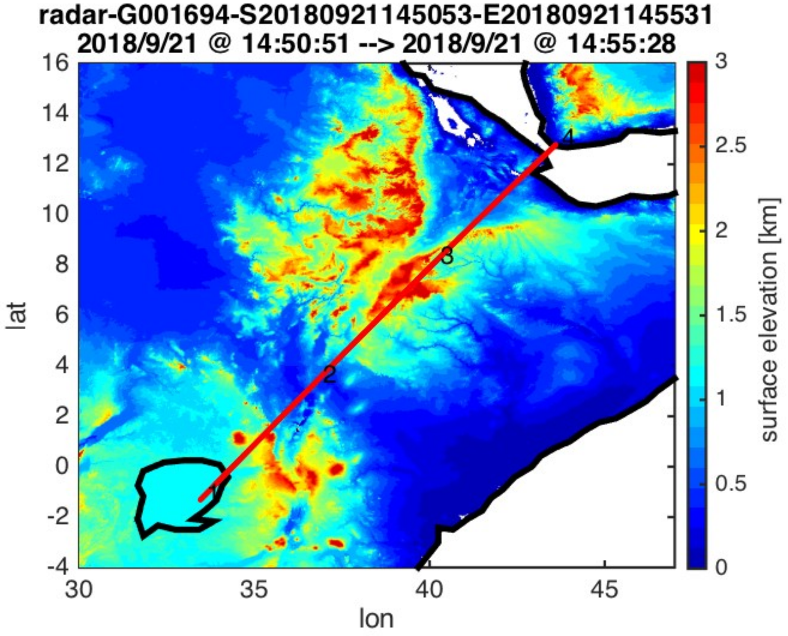


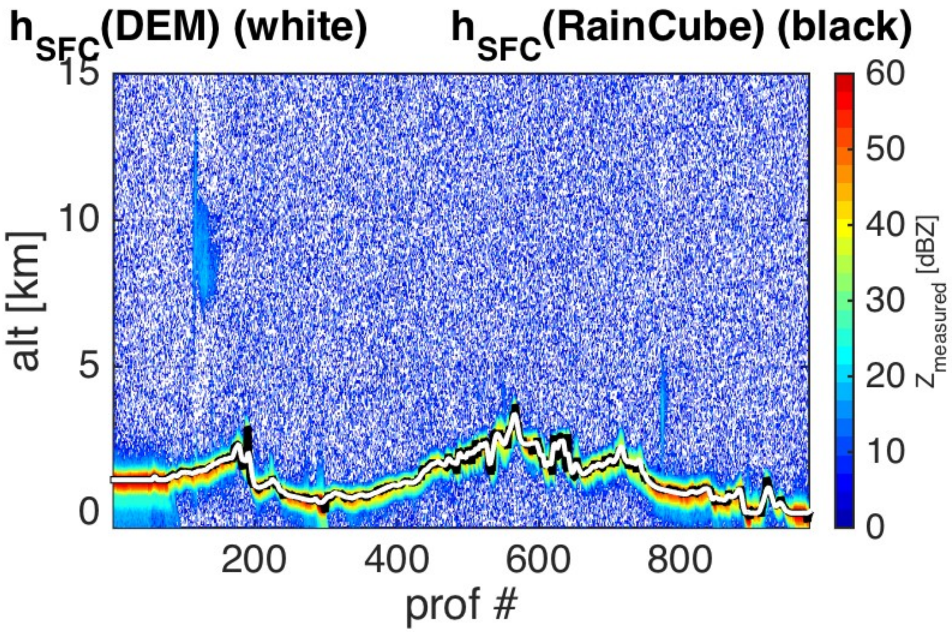
Surface reflectivity from GPM DB



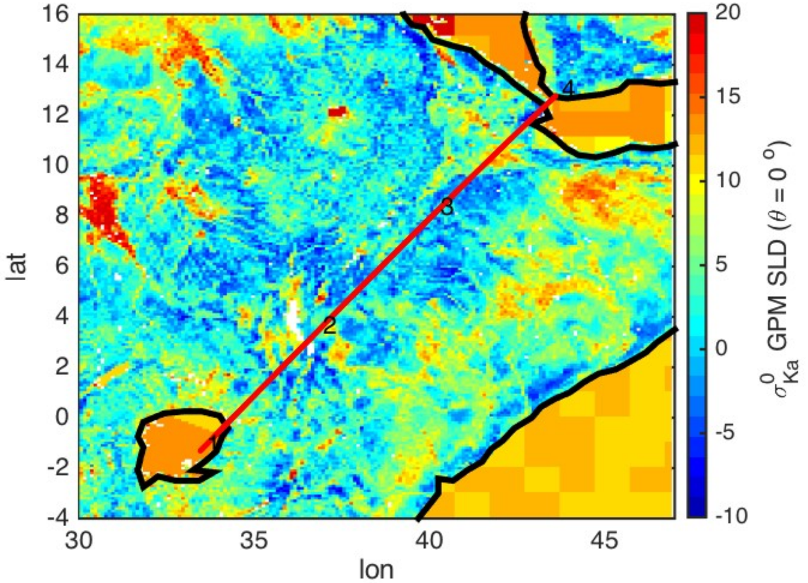
Surface reflectivity (1/2) Horn of Africa/Red Sea

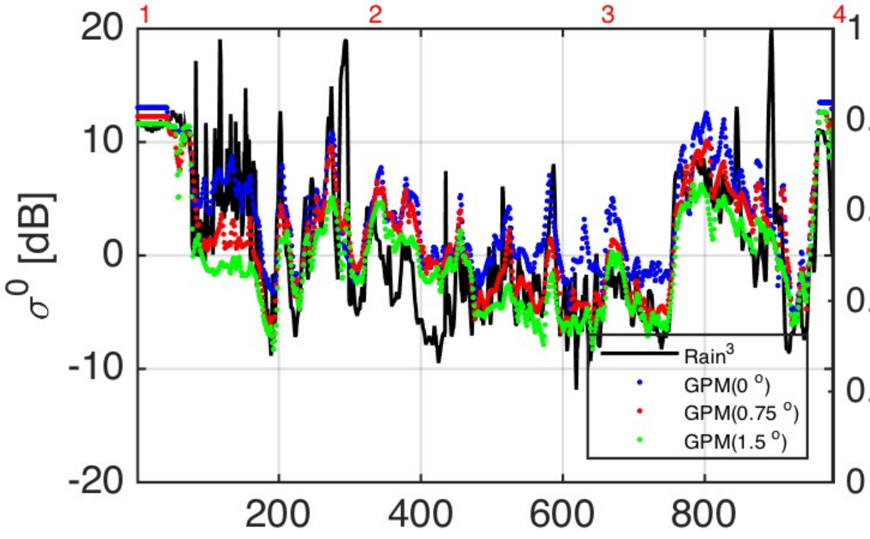
High-resolution DEM from CloudSat





GPM surface reflectivity

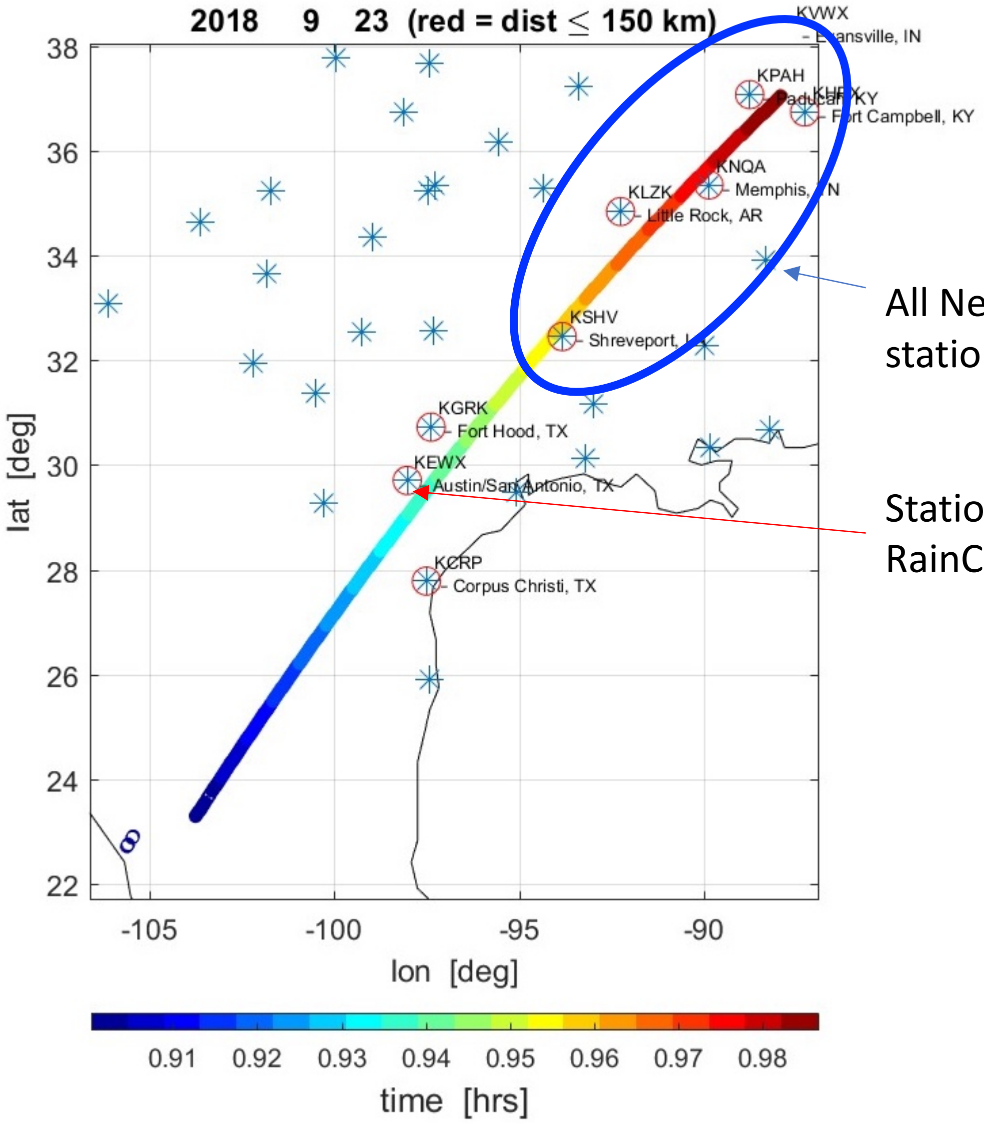




surface reflectivity
- Raincube (black)
- GPM for various incidence angles

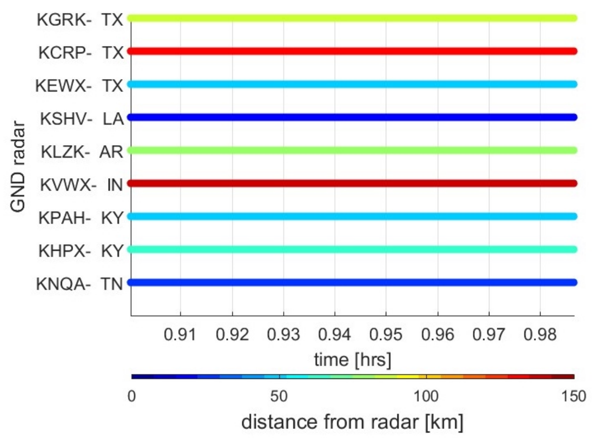
Granule G001728: Memphis, TN; Little Rock, AR

Validation



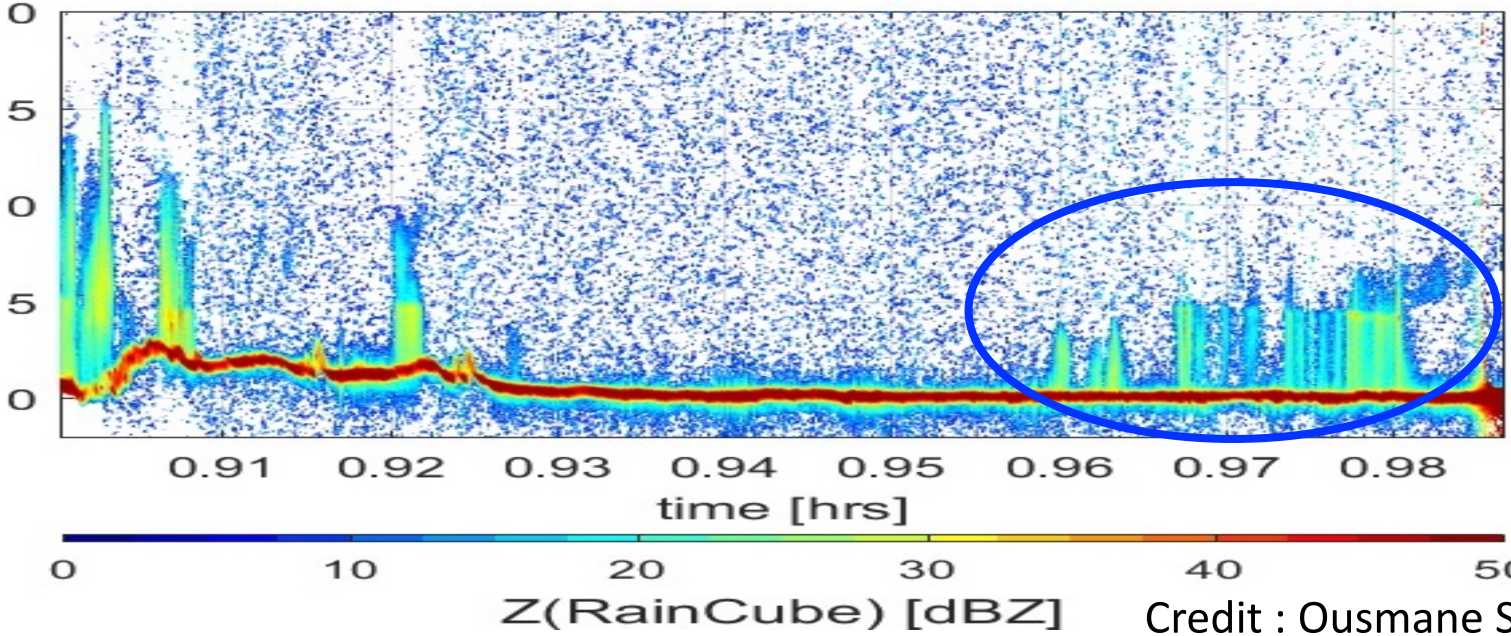
All Nexrad stations (*)

Stations within 150 km of RainCube footprint (o)



Distance station to RainCube footprint (color = distance)

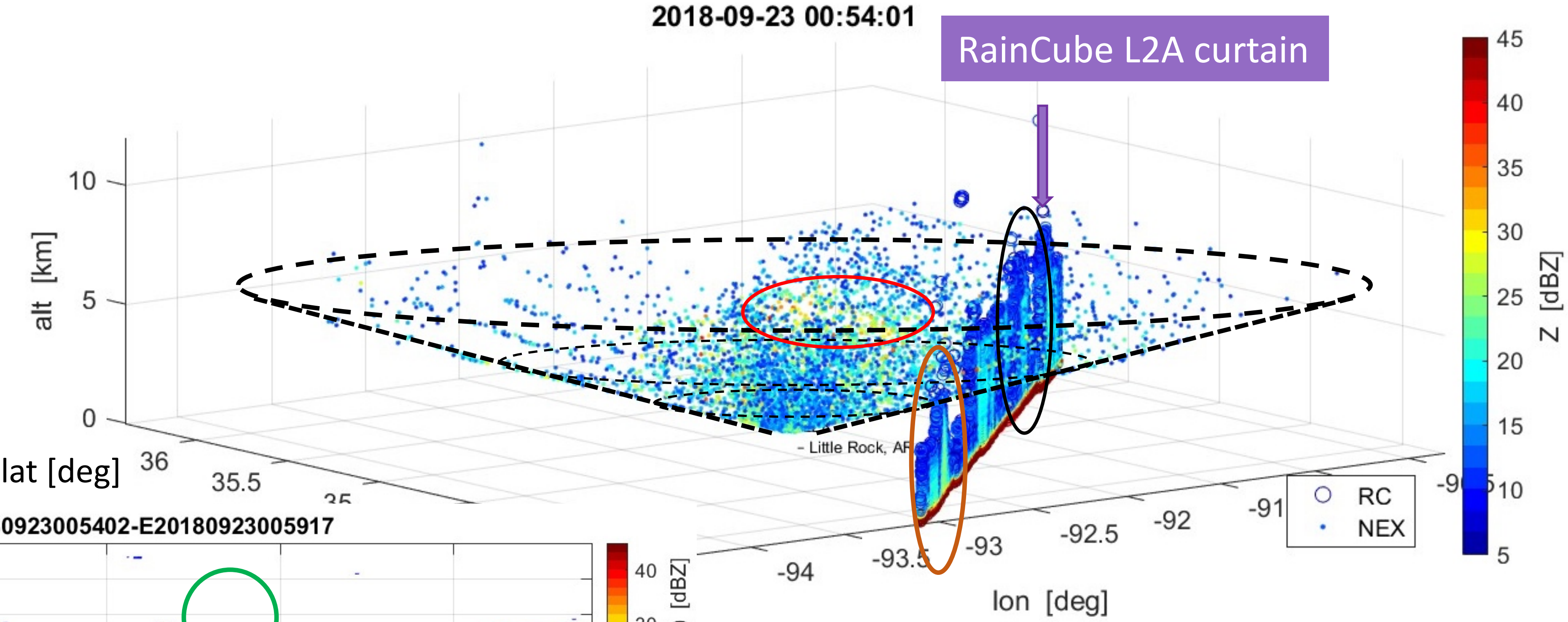
RainCube L2A curtain

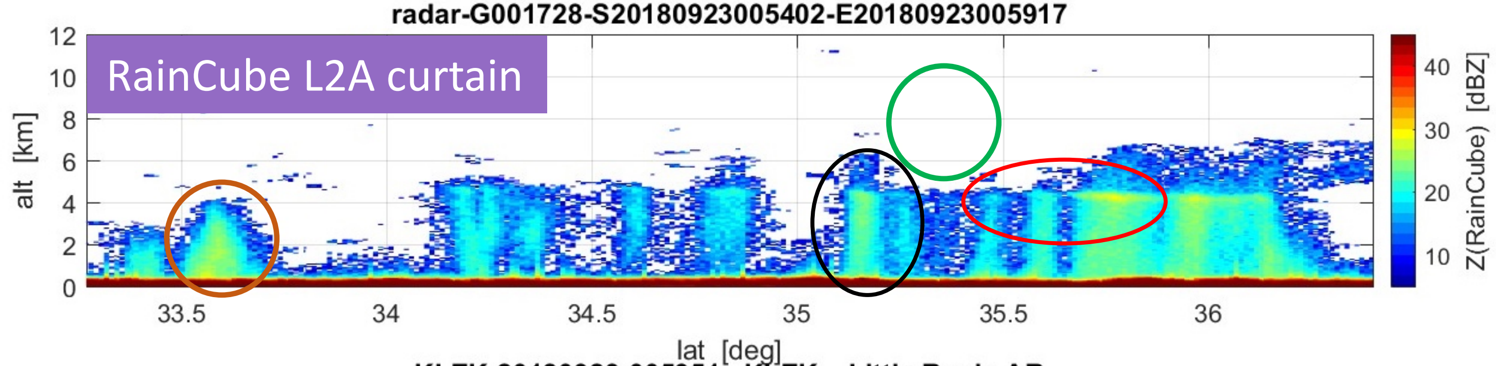


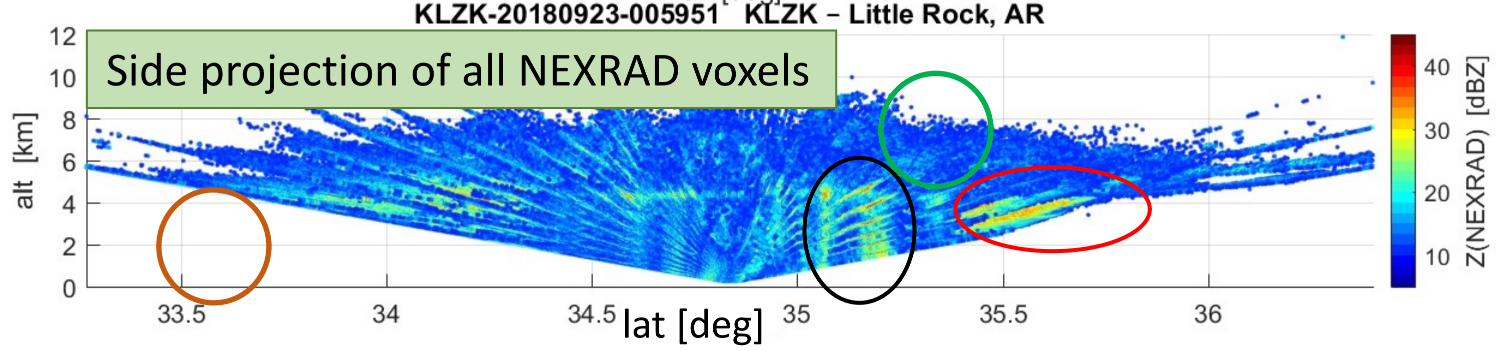
Credit : Ousmane Sy

Granule G 001728: Memphis, TN; Little Rock, AR

Little Rock, AR
@ 00:58:25







Rainshower
First order assessment of features and calibration is reasonable: NEXRAD is S-band, different geometry, ~2 minute difference in time.

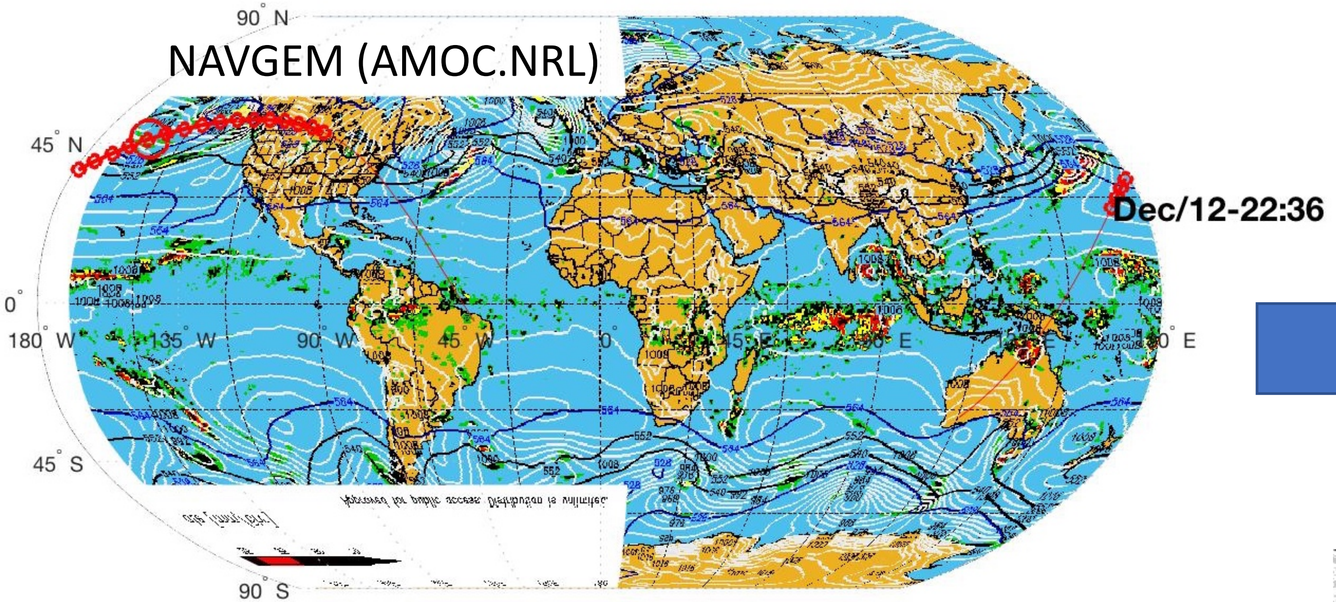
Bright band features at the melting layer
Current extractor captures also NEXRAD Voxels that are displaced from RainCube, the brightest spots were not within RainCube footprint. Visualization tool being refined.

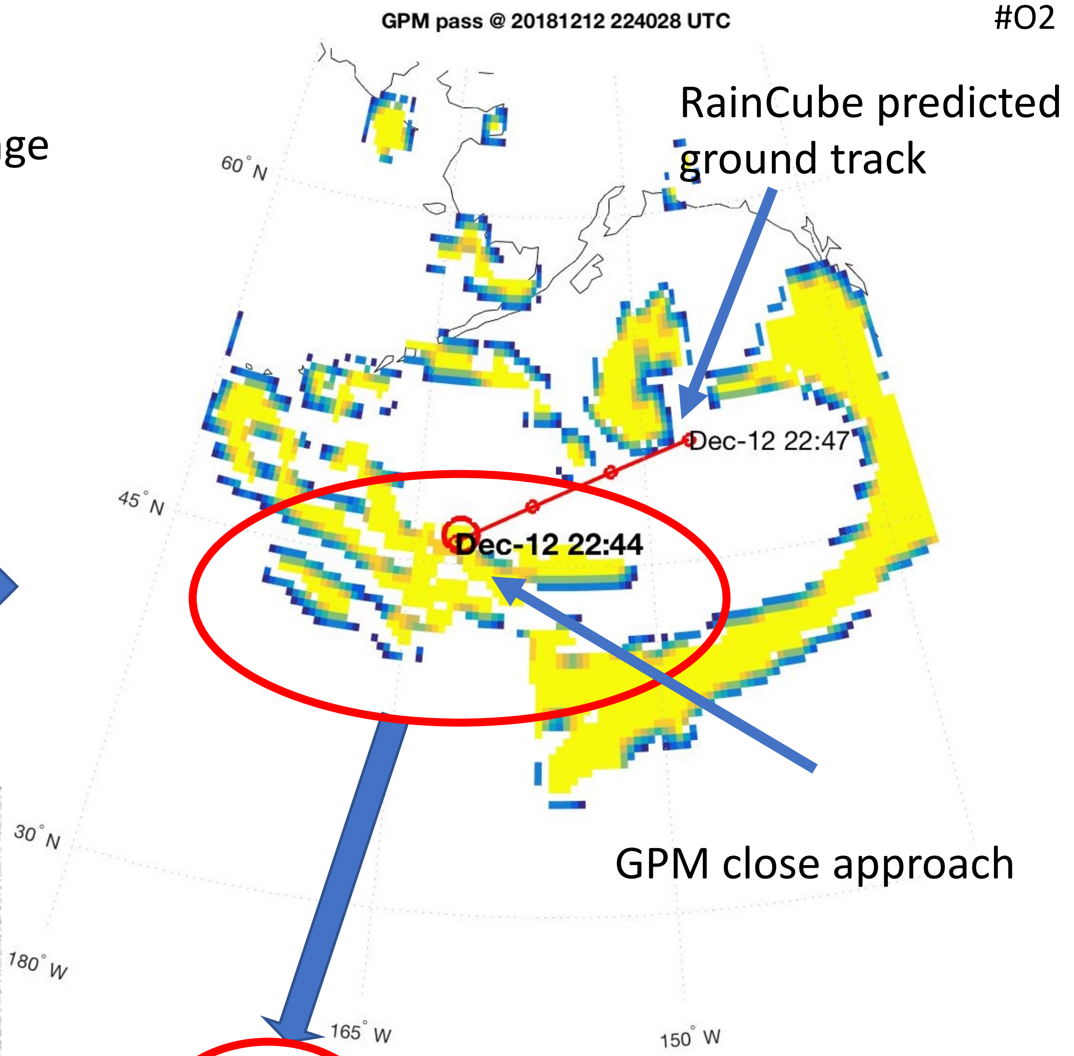
Frozen hydriometeors above the melting Layer
Not visible in RainCube because below the sensitivity.

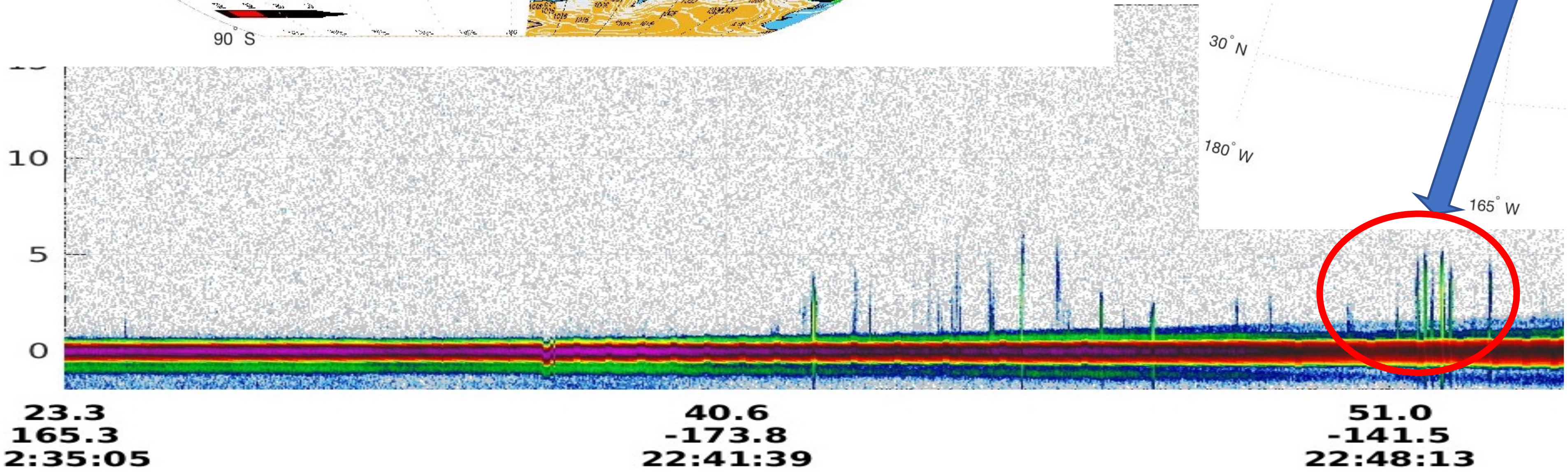
Warm Rain cell
Not visible in NEXRAD because entirely under the lowest elevation beam.

WEDNESDAY Dec 12

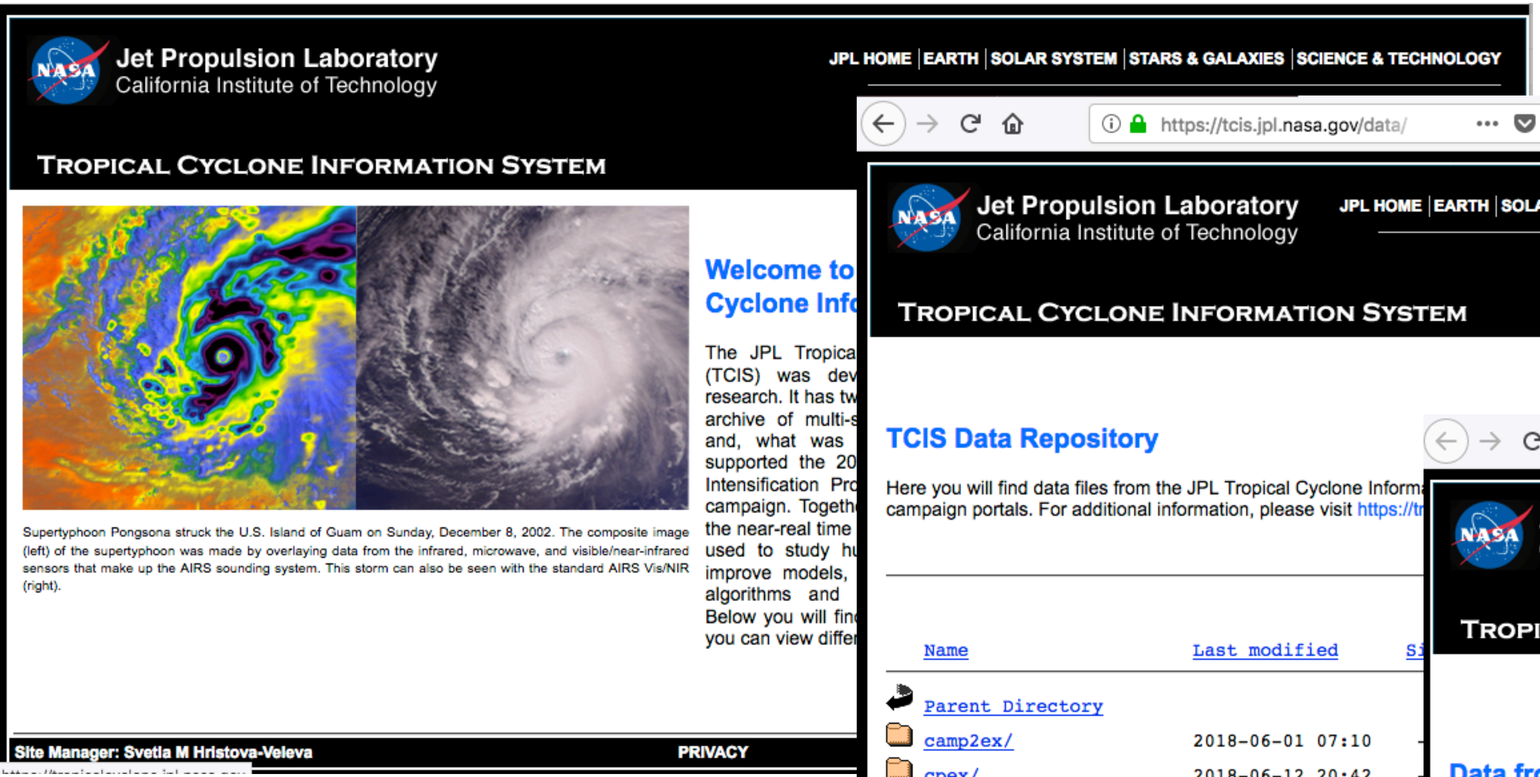
Tentative case with GPM over the North Pacific : GPM @ 2240Z, RC @ 2244Z.
High probability of precipitation, out of range of ground validation.

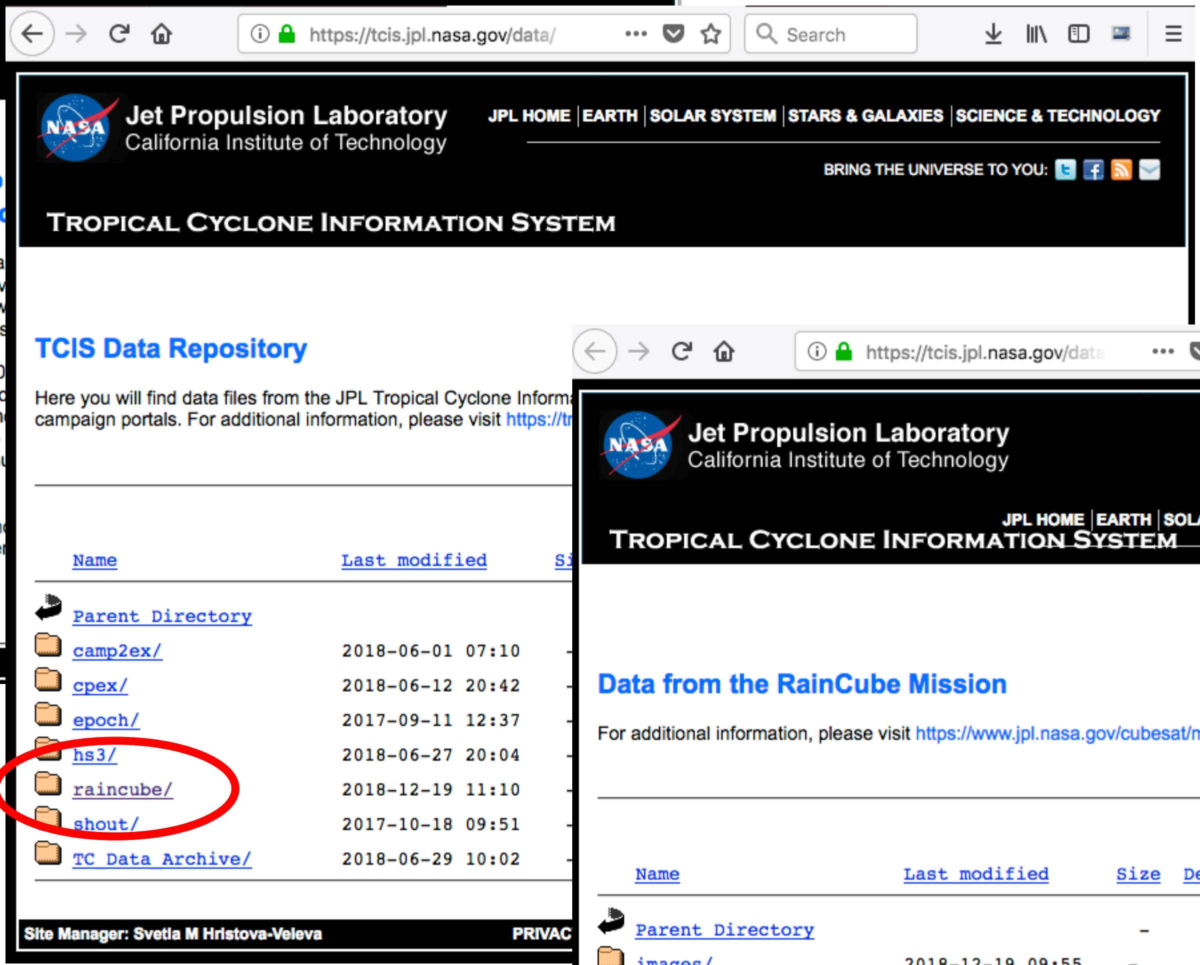


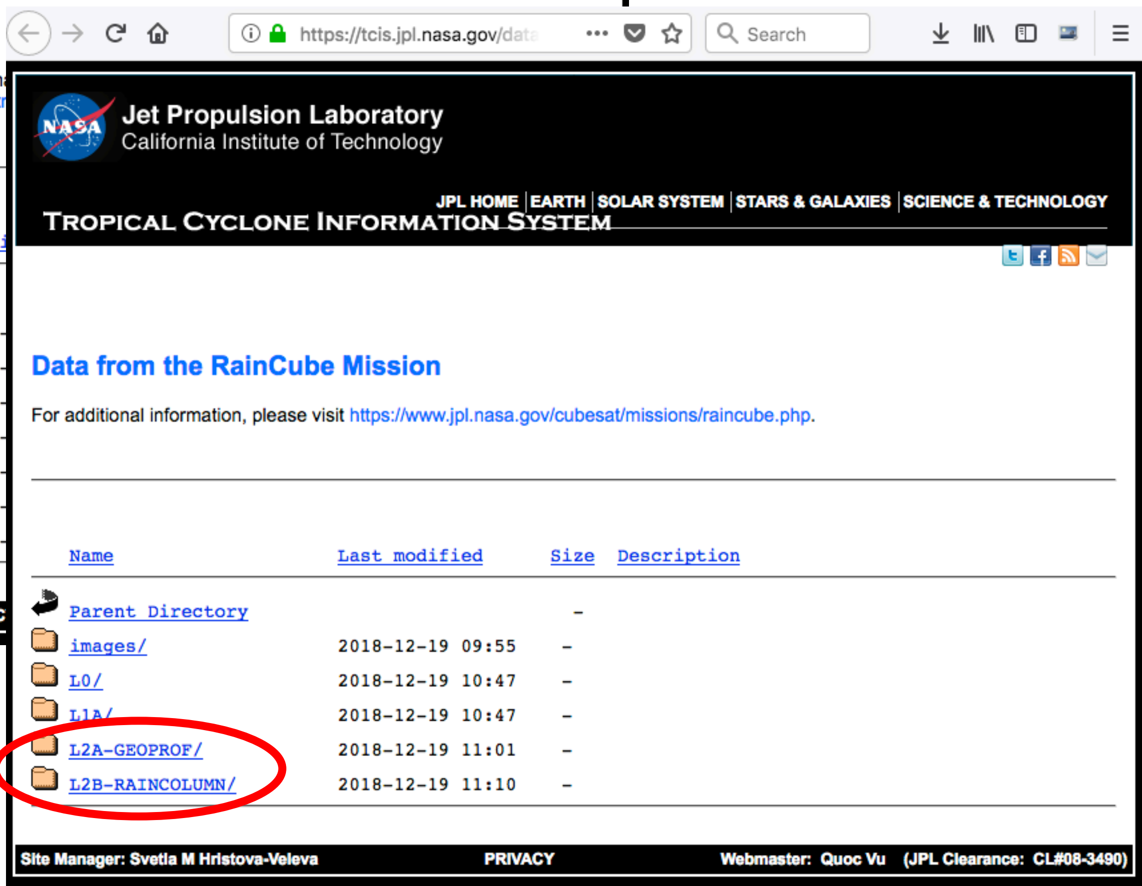




TCIS portal will host RainCube data







The Tropical Cyclone Information System will host RainCube data.

Huge thank you to PI : Svetla Hristova-Veleva, Site Administrator Quoc Vu, and Data Manager Brian Knosp)

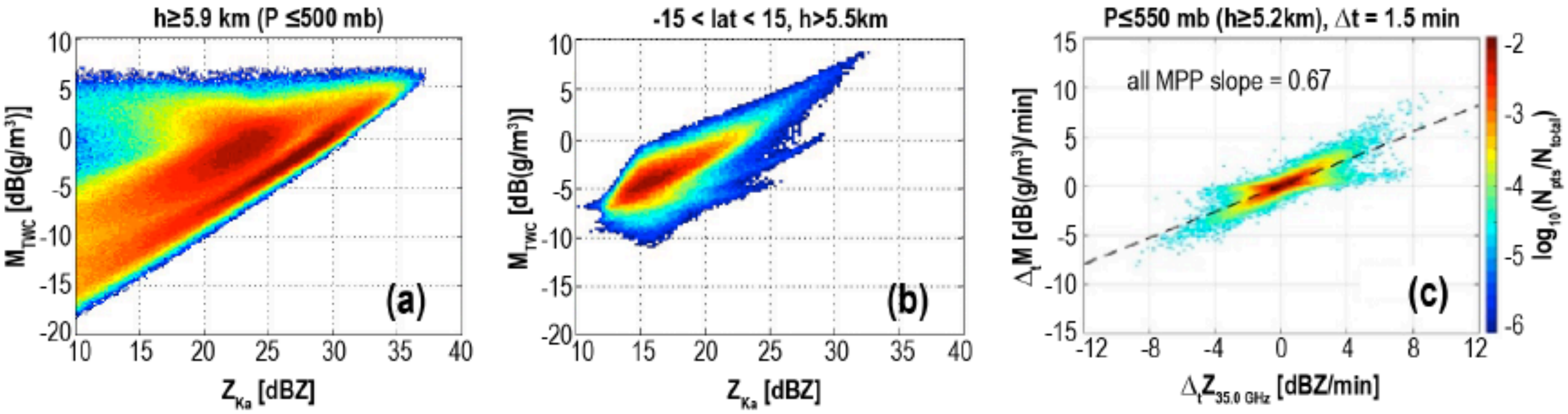
Tested posting data and accessing through url.

L2 Data will be made public when QC is satisfactory.

No plan to open L0 and L1 data to the public.

What’s next ?

To target the original science need,
we need to deploy more than one…



Time difference Ze measurements more directly relate to time change of condensed mass (M) than does Z relate to M (a) Ze-M relationship above 5.9km from simulations of a tropical storm by a CRM with four different versions of microphysical schemes. (b) The Ze-M relation where the coefficients are regionally tuned to M retrieved by GPM product for a 5-day period (4–8 August 2015). The difference between (a) and (b) illustrates the anticipated effect of including GPM-based a priori data to constrain the Ze-M relationships. (c) The ΔZe-dlnM/dt relationship above 5.2km derived from the CRMDB applied to multiple cloud physical schemes.

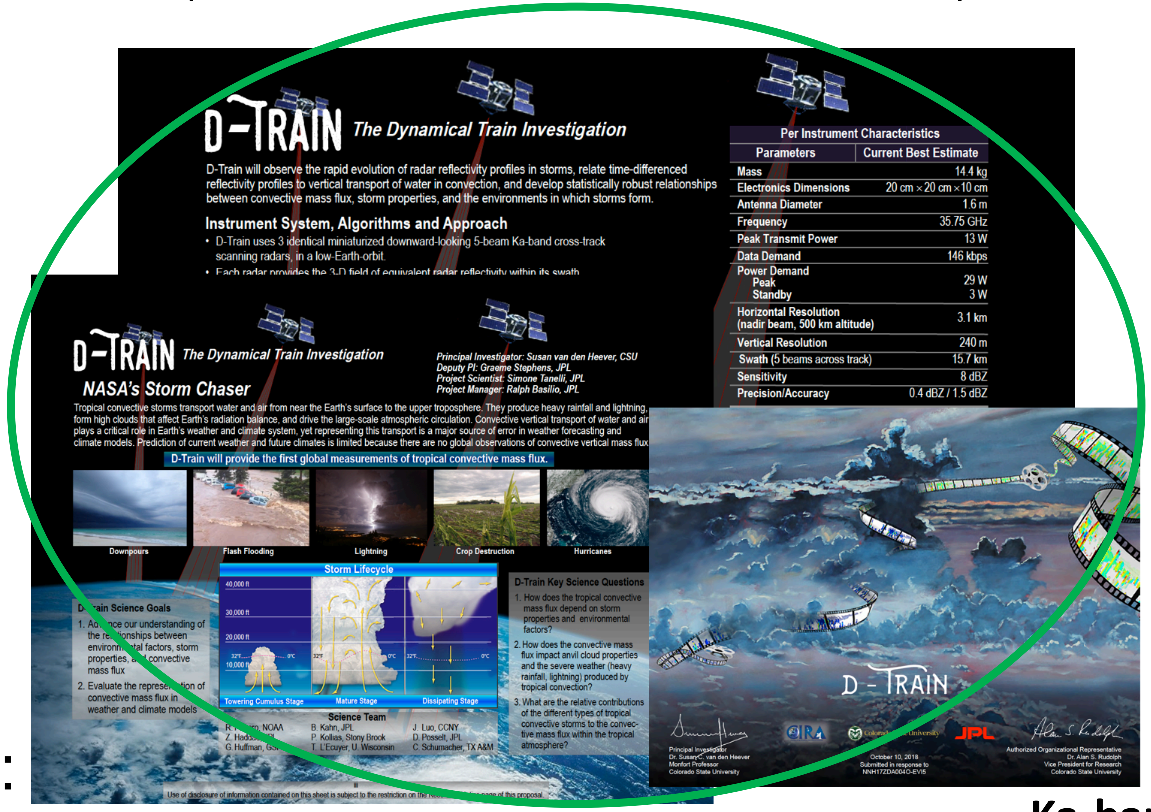
See also:

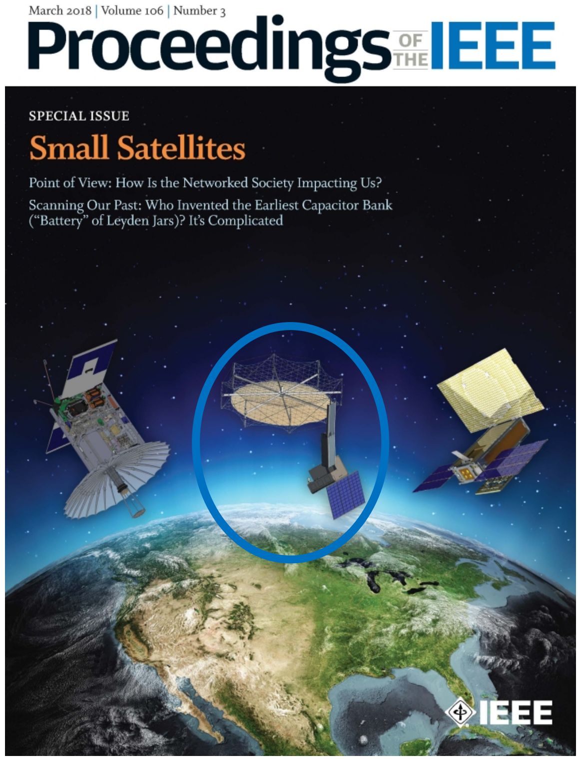
1. *Haddad, Z.S., O.O. Sy, S. Hristova-Veleva, G.L. Stephens; Derived Observations from Frequently-Sampled Microwave Measurements of Precipitation. Part I: Relations to Atmospheric Thermodynamics. IEEE Trans. Geosci. Rem. Sens. vol. 55, pp. 2898-2912, 2017*
2. *Sy, O.O.; Haddad, Z.S.; Stephens, G.L.; Hristova-Veleva, S.; Derived Observations from Frequently-Sampled Microwave Measurements of Precipitation. Part II: Sensitivity to Atmospheric Variables and Instrument Parameters. IEEE Trans. Geosci. Rem. Sens. vol., pp. 1-13. 2017*

What's next ?

- Constellation of RainCube's "as is"
  - Analyze the current dataset to demonstrate the potential and the limitations of the current system in addressing specific science questions.

- Constellation with a larger/scanning antenna
  - To address a larger set of science questions
  - Development of technologies and of mission concepts is ongoing





Ka-band ESTO InVEST and ACT programs

	6U	12 U	50 kg
Antenna size [m]	0.5	1.0	2.0
Sensitivity [dBZ]	15	5-10	0-5
Hor Resolution [km]	8	4	2
Range Res [m]	250		
Beams	1	1-3	1-5
RF Power [W]	10	10-20	10-40

- Constellation with other Radars and Radiometers:
  - A study team in the Earth Science Decadal Survey 2017 will consider RainCube-like constellations for measurements of convection and precipitation
  - Higher frequency versions of RainCube for cloud and water vapor observations

- Planetary applications
  - An evolution of this instrument could support altimetry and cloud and precipitation on planetary targets

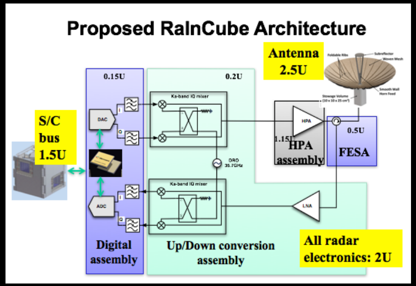
Multi-Application SmallSat Tri-band Radar (MASTR)

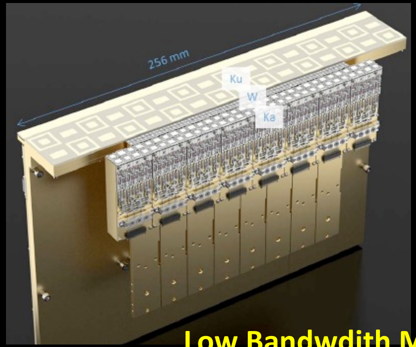
What's next ?

miniKaAR
back end
reduce # of parts
Simple

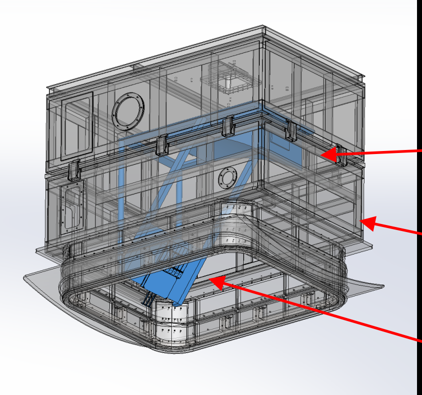
+

3CPR
antenna scheme
scanning
Agile





Airborne Prototype
airMASTR
ESTO IIP – 2017/19 – PI: M. Sanchez-Barbetty



Planned first flight :
Nov 2019

Reflector (3CPR EM)

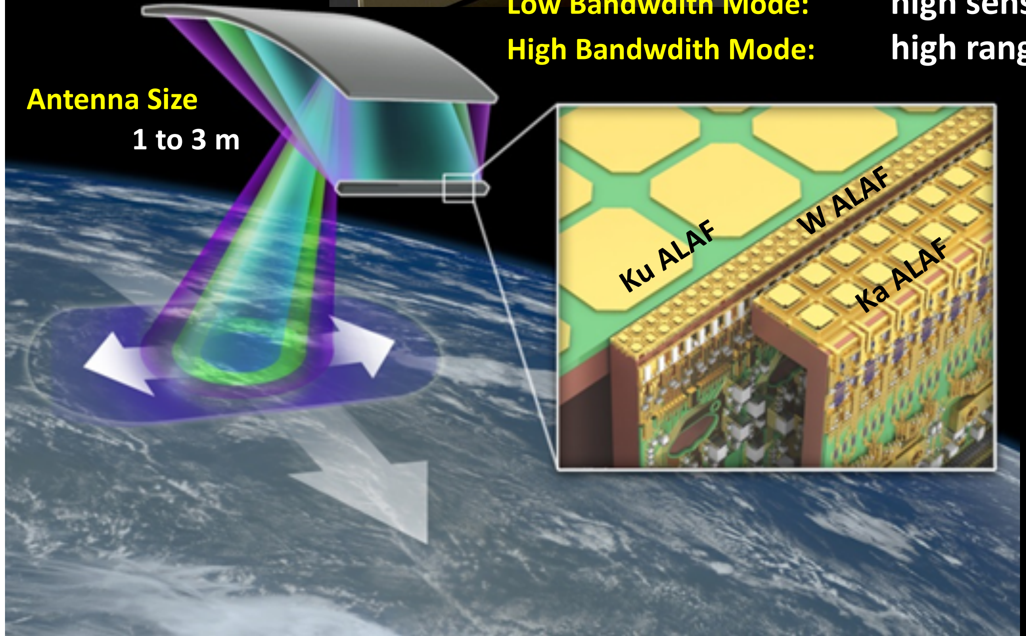
NASA DC-8 Pressure box
(same position as APR-3)

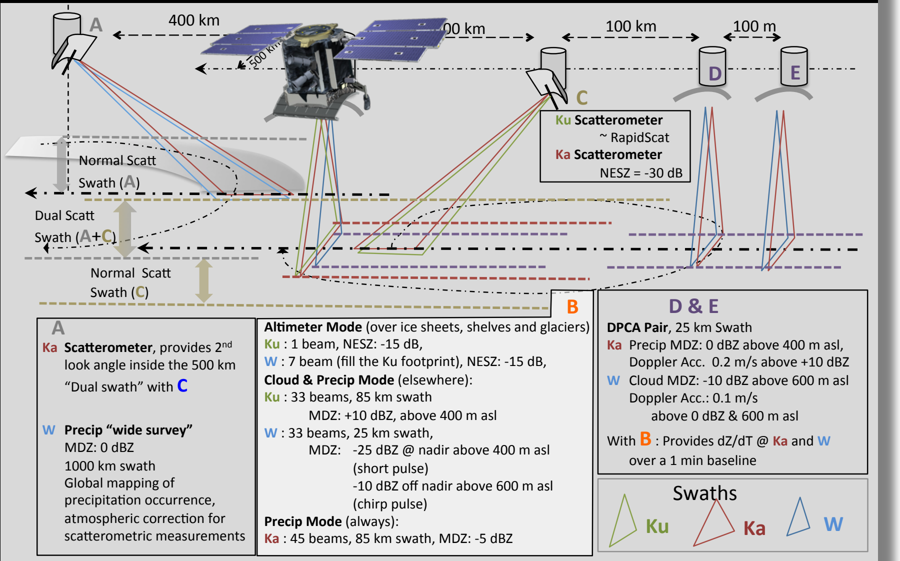
Phased Array Feed
(30 x 4 x 20 cm)

Low Bandwdith Mode: **high sensitivity *(Clouds and Precipitation, Scatterometry)***

High Bandwdith Mode: **high range res *(Altimetry, Snow Depth, Sea Ice freeboard)***

Antenna Size
1 to 3 m





You can now follow RainCube on NASA's Eyes

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